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Wastewater Treatment Technology Documentation for Toxaphene Manufacture

Midwest Research Inst.

Prepared For
Environmental Protection Agency

February 6, 1976

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MRI REPORT

EPA-440/9-76-013

WASTEWATER TREATMENT TECHNOLOGY DOCUMENTATION FOR TOXAPHENE MANUFACTURE

FINAL REPORT
February 6, 1976

Contract No. 68-01-3524
MRI Project No. 4127-C

EPA Project Officer
Mr. Ralph H. Holtje

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U.S. Environmental Protection Agency
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WASTEWATER TREATMENT TECHNOLOGY DOCUMENTATION FOR TOXAPHENE MANUFACTURE

by

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

FINAL REPORT
February 6, 1976

Contract No. 68-01-3524
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PREFACE

This is one of four reports on pesticide-containing wastewaters prepared by Midwest Research Institute for the Office of Water Planning and Standards. These reports concern the wastewater treatment technology involved in the manufacture of aldrin/dieldrin, endrin, toxaphene, and DDT. This report is concerned with toxaphene.

These reports were prepared by Dr. Alfred F. Meiners, Mr. Charles E. Mumma, Mr. Thomas L. Ferguson, and Mr. Gary L. Kelso. This program (MRI Project No. 4127-C) has been under the general supervision of Dr. Edward W. Lawless, Head, Technology Assessment Section. Dr. Frank C. Fowler, President, Research Engineers, Inc., and Mr. William L. Bell, President, Arlington Blending and Packaging, acted as consultants to the program.

Approved for:

MIDWEST RESEARCH INSITUTE

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L. J. Shannon, Assistant Director
Physical Sciences Division

February 6, 1976

INTRODUCTION

Midwest Research Institute (MRI) has performed a comprehensive examination of the wastewater treatment technology applicable to aldrin/dieldrin, endrin, DDT, and toxaphene. The work was performed for the Environmental Protection Agency (EPA) under Contract No. 68-01-3524.

The basic objectives of the program were: (a) to perform an examination of the wastewater management practices currently employed in the manufacture of the specified pesticide; (b) to examine the state of the art of potential wastewater treatment processes that might be applicable to this industry; and (c) to select those processes that would be applicable to EPA toxic pollutant control technology requirements. Of special interest was the cost of existing and proposed wastewater treatment methods.

This report concerns the wastewater treatment technology for toxaphene manufacture.

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TOXAPHENE MANUFACTURE

SECTION I

SUMMARY

Toxaphene (chlorinated camphene) is produced in the United States by four companies: Hercules, Inc. (at Brunswick, Georgia); Tenneco Chemicals, Inc. (at Fords, New Jersey); Riverside Chemical Company (at Groves, Texas) and Vicksburg Chemical Company (at Vicksburg, Mississippi). Actual toxaphene production rates are not available; however, total production in the United States is estimated to be 80 to 110 million pounds.

Toxaphene is produced in essentially the same manner by all domestic producers, that is, by the chlorination of camphene. This production method results in the formation of relatively large quantities of by-product hydrogen chloride (about 0.5 lb/lb toxaphene). The hydrogen chloride is absorbed in water, generating hydrochloric acid. The generation of the acid creates a major disposal problem. Tenneco, Riverside, and Vicksburg have reported that they sell practically all of the acid generated. Hercules neutralizes and discharges a large portion of the acid generated. A summary of toxaphene production and wastewater characteristics is presented below.

	Estimated 1975 toxaphene production (millions of pounds)	Average wastewater flow from toxaphene production		Average daily toxaphene discharge in plant effluent	
		gpm	gal/lb product	lb/day	ppb
Hercules	50-80	167	1.1-1.8	0.27	114
Tenneco	9-11	0.07	0.003-0.004	< 0.05	< 6
Riverside	8-10	5.8	0.30-0.38	0.032	320
Vicksburg	9-11	10	0.48-0.58	Unknown	Unknown

Information sources and methods for calculating the above data are detailed in the report.

The above data show that Hercules produces a relatively large quantity of wastewater compared to the other producers. Hercules employs a toxaphene wastewater system which includes neutralization of by-product hydrogen chloride followed by adsorption and sedimentation processes. The other manufacturers sell practically all of the by-product hydrogen chloride as hydrochloric (muriatic) acid. The wastewaters generated by Tenneco, Riverside, and Vicksburg are primarily spent caustic liquor from scrubbers used to absorb excess hydrogen chloride in the hydrochloric acid production process. The volume of spent caustic liquor is very small compared to the volume of neutralized hydrochloric acid produced by Hercules.

Because of the relatively large quantity of water produced by Hercules, and also because of the relatively high concentration of toxaphene in this wastewater, alternate methods may be required for treating the Hercules effluent. Four treatment systems appear to be the most promising for this purpose: (a) a resin adsorption system, (b) a reductive degradation system,

(c) the resin adsorption and reductive degradation systems in series, and (d) an activated carbon adsorption system. These systems have been examined in this report for their potential usefulness in the treatment of wastewater from the Hercules manufacturing process. The characteristics of this wastewater have been examined and estimates have been made of the expected quality of the effluents produced by the application of each alternate treatment system to this wastewater.

Only laboratory-scale data are available concerning the applicability of these alternate systems to toxaphene wastewaters. None of the alternate systems have been operated under conditions which approximate actual use, nor have they been developed to the point where a determination of operating conditions or costs can be made with a high level of confidence. However, MRI believes that these treatment systems would be technically feasible based upon (a) the limited available experimental data concerning the effectiveness of these treatment systems in removing toxaphene and related compounds from water, (b) the opinions of experienced research personnel, and (c) a consideration of the similar chemical and physical properties of toxaphene compared to those of other chlorinated pesticides which have been demonstratably removed from wastewater.

The wastewater treatment system at Hercules has been examined in some detail. The cost of the existing system at Hercules and the costs of the four alternate wastewater treatment systems have been estimated. Cost estimates have been made for two flow rates, 200 and 300 gpm; these flow rates

are (a) the approximate average effluent flow rate to the present treatment system, and (b) the design flow capacity of that system. The quality of the present effluent has been compared to the expected quality of the effluent from each alternate system. This information concerning effluent quality and costs is summarized on the following page.

The cost estimates were based upon conceptual systems which required initial sedimentation and filtration steps. Since the present Hercules system employs sedimentation, a question arises concerning whether or not the estimated costs of the alternate systems would be add-on costs for Hercules. If the alternate systems were added to the present Hercules system, no additional sedimentation step would probably be required because of the extensive sedimentation system in place at Hercules. However, because of the nature of the alternate systems, an additional filtration step would probably be required to remove suspended solids. (The average concentration of suspended solids was 57 ppm between September 1974 and March 1975.) Furthermore, because these solids remained after an extensive sedimentation step, a sophisticated and costly filtration system might be required in order to achieve a substantial reduction of suspended solids.

Sedimentation and filtration represent a significant portion (25 to 45%) of the estimated capital equipment costs for the alternate systems, and the filtration step is four or five times more costly than the sedimentation step. Thus, even though the sedimentation step might be eliminated, the total capital equipment cost would probably not be greatly reduced.

SUMMARY OF ESTIMATED COSTS FOR TOXAPHENE WASTEWATER TREATMENT SYSTEMS
(Hercules Plant, Brunswick, Georgia)

	Wastewater flow rate (gpm)	Toxaphene in treated effluent ppb	Toxaphene in treated effluent lb/day	Installed capital equipment cost	Annual operating cost	Cost per pound of toxaphene product[a/]
Hercules' system	181 (8/74)	203	0.44	$800,000	$300,000	$0.0060
	146 (2/75)	58	0.10	800,000	300,000	0.0060
Resin adsorption	200	1.4	0.0034	586,200	324,300	0.0065
	300	1.4	0.0050	790,400	433,200	0.0087
Reductive degradation	200	< 3	< 0.0072	350,700	154,100	0.0031
	300	< 3	< 0.0108	433,700	181,800	0.0036
Resin adsorption plus reductive degradation	200	0.1	0.0002	731,600	410,300	0.0082
	300	0.1	0.0004	955,900	537,500	0.0108
Activated carbon adsorption						
30 min contact time	300	< 5	< 0.018	617,000	194,200	0.0039
60 min contact time	300	< 5	< 0.018	794,000	232,500	0.0047

a/ Based upon an annual production of 50 million pounds of toxaphene.

Furthermore, if a sophisticated filtration step was required, there might even be an increase in costs. Therefore, we conclude that the estimated costs of each of the alternate systems would be approximately equal to the cost of adding that system to the existing Hercules system.

The effluent from the present Hercules system contains an average of 57 ppm suspended solids and 114 ppb toxaphene (the solubility of toxaphene has been reported to be 400 to 3,000 ppb). Estimates indicate that the concentration of toxaphene in the precipitated sludge is approximately 0.02%. If it is presumed that the amount of toxaphene adsorbed on the suspended solids is about the same as the amount adsorbed on the sludge, a 10% reduction in the amount of toxaphene in the effluent would be achievable if the suspended solids could be completely removed from the effluent stream.

Very few data are available upon which to base the design of a filtration system which would accomplish the removal of the suspended solids. If a simple sand filtration system is sufficient, the estimated capital equipment cost would be $130,000 to $160,000. If fine filtration is required, the estimated capital equipment cost would be about $225,000, but a sand filtration system would probably also be required as an initial step. Operating costs for each of these systems would be approximately 15% of the capital equipment cost.

SECTION II

CHARACTERIZATION OF INDUSTRY

Toxaphene (chlorinated camphene) is produced at four plants in the United States which differ considerably in their operating characteristics. A summary of production rates, average wastewater flows and average daily toxaphene discharges is presented in Table 1. Detailed descriptions of these plants and their wastewater operations are presented in the following four sections.

HERCULES, INC.

General

The Hercules, Inc., chemical plant at Brunswick, Georgia, is about 50 years old (Ferguson and Mumma, August 1975). The plant produces about 120 products (SIC 2861 and SIC 2879-secondary) and the principal raw material is pine stumps (Ferguson and Mumma, August 1975).

The Hercules plant produces resin, terpenes and their derivatives from pine stumps. The plant uses from 1,000 to 1,900 tons of stumps per day. The stumps are washed, ground into chips and stored. The chips are then extracted with a solvent (methyl isobutyl ketone) under heat and pressure. The mixture of solvent and dissolved resin is drained from the

Table 1. SUMMARY OF PRODUCTION RATES AND WASTEWATER CHARACTERISTICS FOR TOXAPHENE MANUFACTURERS

	Estimated 1975 toxaphene production (millions of pounds)	Average wastewater flow from toxaphene production		Average daily toxaphene discharge in plant effluent	
		gpm	gal/lb of product	lb/day	ppb
Hercules	50-80[a]	167[b]	1.10-1.75[c]	0.27[d]	114[b]
Tenneco	9-11[a]	0.07[e]	0.003-0.004[c]	< 0.05[b]	< 6[e]
Riverside	8-10[a]	5.8[g]	0.30-0.38[c]	0.032[h]	320[h]
Vicksburg	9-11[a]	10.0[i]	0.48-0.58[c]	Unknown	Unknown

a/ MRI estimate.
b/ Hicks (1975). See Table 2.
c/ Calculated from production estimates and wastewater flow rate.
d/ Calculated from data of Hicks (1975). See Table 2.
e/ Worley (1975).
f/ Calculated from "Commingled" waste stream (003) flow rate (1.01 million gallons per day) and average toxaphene concentration < 6 ppb (Worley, 1975).
g/ NPDES, TX0062448 (1975).
h/ The NPDES discharge limitation (TX0062448) is 0.04 lb/day. September 1975 analytical data supplied by a Riverside representative indicates an average monthly discharge of 0.032 lb/day. On the basis of a 12,000 gal/day (5.8 gpm) discharge, the calculated toxaphene concentration is 320 ppb.
i/ Enviro-Labs (1975). See text concerning Vicksburg wastewater characteristics.

extractors and pumped to the refinery. The spent chips are burned in the power plant boilers. Solvent, turpentine, and pine oil are removed from the mixture by distillation. The crude rosin is subsequently refined further into rosin derivatives. The solvent is recovered and returned to the extractor. Mixed turpentine and pine oil are routed to the still house for further separating and fractionating. Toxaphene insecticide is manufactured from α-pinene in a separate process (Lair and Bruner, 1975).

Normally, the plant operates 7 days/week, 24 hr/day. However, since the latter part of February 1975, the plant has been operating on a split 10-day-on 4-day-off schedule as follows (Lair and Bruner, 1975):

- Primary operations (wood milling, extraction, and main portion of the power hours) continuous until February 28, then the 10 day working schedule commencing March 5, 1975.
- Secondary operations (toxaphene plant, and other conversion operations) continuous until February 23, then the 10 day working schedule commencing February 26, 1975.

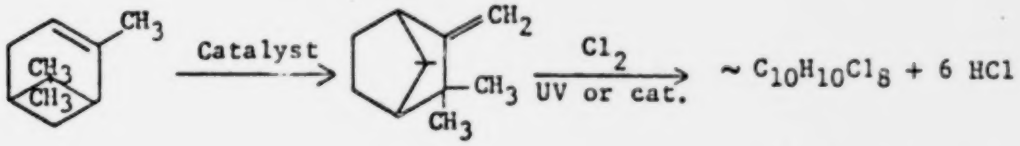
Toxaphene Manufacture

Hercules, Inc., has produced toxaphene at the Brunswick, Georgia, plant since 1948 and was its first manufacturer. Hercules' patents on toxaphene expired in the late 1960's.

The estimated annual production of toxaphene at the Hercules plant in 1975 is 50 to 80 million pounds (MRI estimate).

Toxaphene is produced in a series of steps beginning with the raw material α-pinene, which is extracted from pulverized resinous southern pine stumps. Alpha pinene is heated over a catalyst of benzoyl peroxide to form camphene plus bornylene and some α-terpineol which are then chlorinated by liquid chlorine in carbon tetrachloride to produce yellow waxy toxaphene. About two thirds of the final weight of toxaphene is chlorine. Approximately 7 moles of chlorine gas are required per mole of camphene to produce a mole of toxaphene and 6 moles of hydrochloric acid (Ferguson and Meiners, 1974).

The production chemistry for toxaphene manufacture is shown in the following equation (Ferguson and Meiners, 1974):

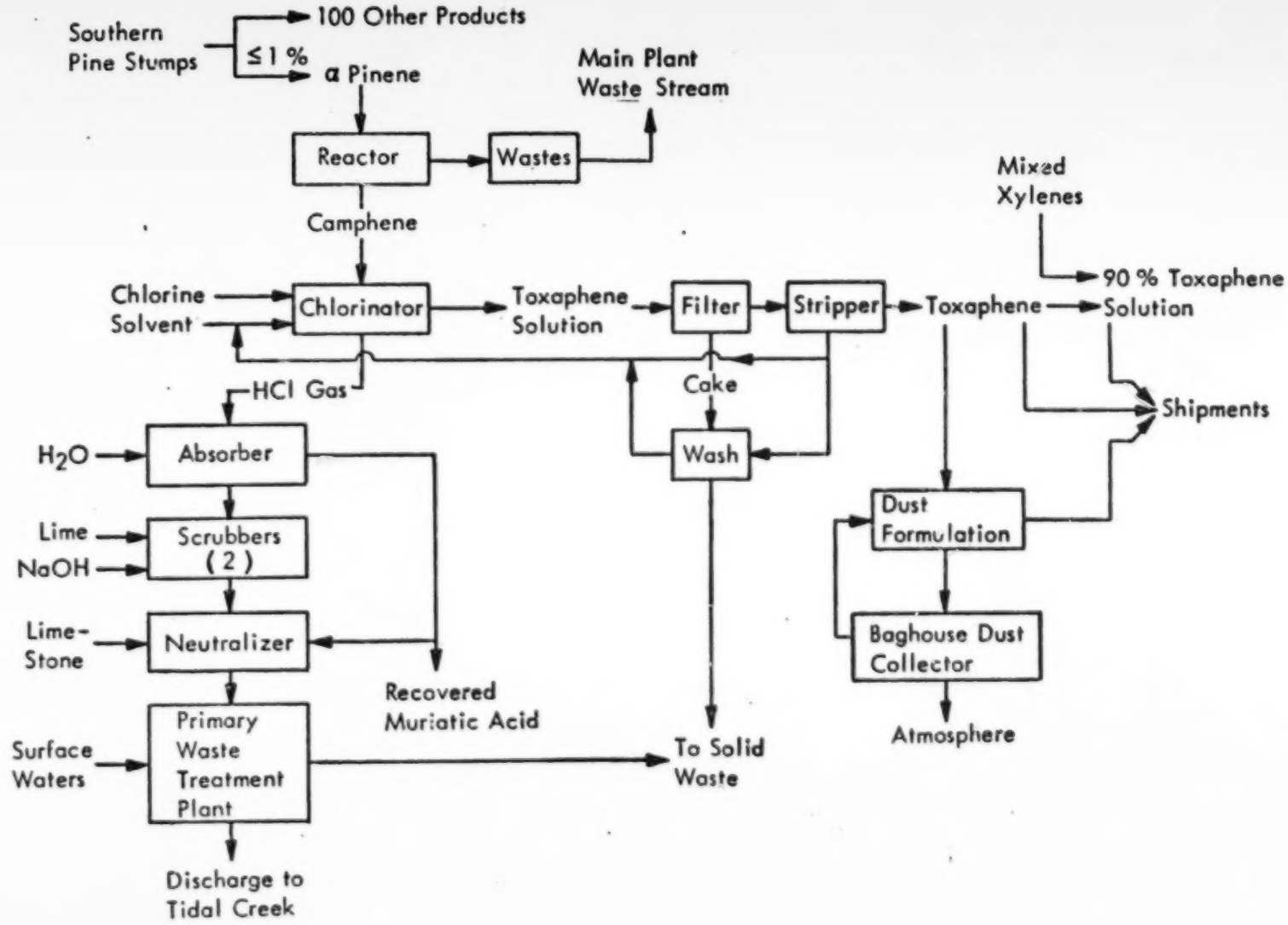


α-Pinene Camphene Toxaphene (mixed isomers and related compounds 67-69% Cl)

A production and waste schematic for Hercules' toxaphene process is shown in Figure 1.

Jett (1975) has reported that Hercules' hydrochloric acid (muriatic acid) by-product is either sold or neutralized. Hicks (1975) has reported that the sources of the process water are deep wells.

Other information concerning toxaphene manufacture at Hercules is shown as follows (Ferguson and Meiners, 1974).



Source: Ferguson and Meiners (1974)

Figure 1. Hercules' production and waste schematic for toxaphene

Raw Materials (Ferguson and Meiners, 1974)

	Material	Received From	Received By	Storage
1.	Camphene	On site from α-pinene		
2.	Cl_2	Six local sources	Tank cars	
3.	Solvent		Tank cars	Tanks
4.	Clay	Georgia	Rail	Silo
5.	NaOH	Georgia	Tank truck	Tanks
6.	Limestone	Georgia	Rail	Silo
7.	Slaked lime	Georgia	Rail	Warehouse

Reaction By-Products (Ferguson and Meiners, 1974)

	Material	Form	Amount Produced (lb/lb AI)	Disposition
1.	HCl	Solution in water	0.53	Sold or neutralized

Other Process Wastes and Losses
(Ferguson and Meiners, 1974)

	Materials	Form	Disposition
1.	Active ingredient	Liquid or solid	Waste treatment system
2.	Solvents		
3.	Camphene production	Liquid	Discharge to tidal creek
4.	Waste from scrubbers		Waste treatment system

Disposition of Technical and Formulated Products
(Ferguson and Meiners, 1974)

	Shipments				
	Technical Product		Formulated Products		
Warehouse Elsewhere	Container	Transportation	Formulation	Container	Transportation
X	¾ Small amount, 250 gal. galvanized drums	Exported via East coast	¾ Most, 90% concentrate; 10% xylene	Tanks, 55 gal., 50-lb bags pelletized	Rail and truck exports

Wastewater Treatment System*

On March 15, 1974, Richard E. Chaddock stated that the Hercules' waste treatment system was based upon the principle that toxaphene in aqueous media adsorbs very strongly to particulates, especially those of soil. In this system, the waste stream to the treatment lagoon is neutralized and the pH carefully controlled (Chaddock, 1974). The inert solids were reported "to consist chiefly of sand, clay and insoluble hydroxides and carbonates." The toxaphene, "strongly adhering to the inert solids, settles out in several lagoons connected in series" (Chaddock, 1974). Data on the "irreversibility" of toxaphene adsorption has been reported by Wisconsin scientists in a study of fish poisoning (Hughes et al., 1970).

On June 24, 1975, Hicks reported that the toxaphene waste treatment system is a physical/chemical system (Hicks, 1975). Hicks (1975) also reported that residual toxaphene is removed from the wastewater by adsorption on inorganic particulate matter and neutralized. Hicks reported that "this process was selected as the best for toxaphene removal and implemented following extensive testing of other methods such as heat treatment, solvent extraction, and the use of other adsorptive media" (Hicks, 1975).

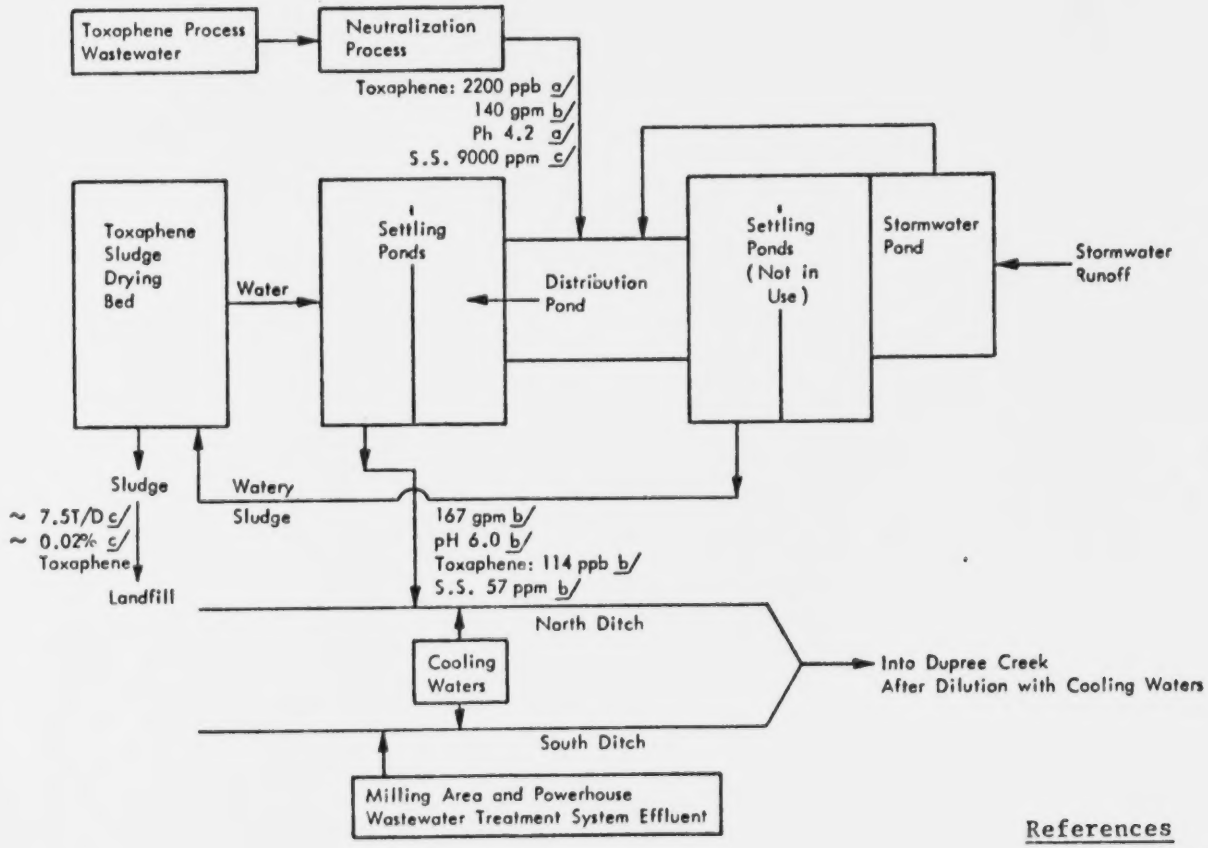
---

* Additional information concerning the Hercules' waste treatment system is provided in Appendix A. The information contained in Appendix A was obtained from an engineering report supplied by Mr. C. L. Dunn, Manager, Ecological Research, Hercules, Inc., to Mr. Richard K. Ballentine, Toxic Substances Branch, EPA, on December 16, 1975. This information was not received in time to be incorporated into the toxaphene manufacture report.

A schematic diagram of the Hercules toxaphene wastewater treatment system at Brunswick, Georgia, is shown in Figure 2. Hicks (1975) has reported that these treatment facilities were built during 1971 to 1974.

Hercules uses a separate treatment system exclusively for wastewater from its toxaphene plant (Ferguson and Mumma, August 1975). Wastewaters from the toxaphene plant are neutralized with caustic and limestone and then pumped into the treatment system shown in Figure 2. This treatment system consists of a distribution pond, four settling ponds (each pond is about 200 ft x 400 ft x 3 ft deep) and a pond used to collect storm water from the toxaphene manufacturing area. A Parshall flume and automatic sampler are used to monitor the effluent from the toxaphene treatment system.

Lair and Bruner (1975) have reported that the Brunswick plant discharges cooling waters, effluent from the toxaphene treatment system, and effluent from the milling powerhouse area treatment system. Discharge is into two ditches, designated by the company as the north and south ditches (Figure 2). These ditches join to form the plant's main outfall (designated 001 on the NPDES Permit No. GA 0003735 (1974)). The combined discharge is into Dupree Creek. Sanitary wastewaters from approximately 950 employees and process wastewaters from the plant's pretreatment facility are discharged into the Brunswick, Georgia, municipal sewerage system (Lair and Bruner, 1975).



References

a/ Ferguson and Meiners (1974).
b/ Hicks (1975).
c/ MRI estimate.

Source: Adapted from Lair and Bruner (1975).
Ferguson and Meiners (1974).

Figure 2. Hercules' toxaphene treatment system at Brunswick, Georgia

Lair and Bruner (1975) have reported that wastewaters from the toxaphene area floor drains and product loading area drains are pumped into the distribution pond along with the toxaphene plant process wastes.

Storm water from the toxaphene production area is pumped to the special storm water pond. Storm waters are pumped slowly from the toxaphene storm water pond into the distribution pond and ultimately into the settling ponds. As indicated in Figure 2, effluent from the settling pond is discharged into the north ditch.

The cooling waters from the toxaphene production area are discharged separately into the north ditch. Jett (1975) has reported that all cooling water is noncontact.

Steam and electricity are generated in a separate remote area so there is no boiler blowdown in the toxaphene area (Hicks, 1975).

Only two of the four settling ponds are used at any one time. Whenever the settling ponds fill up with solids and treatment efficiency decreases, the ponds are taken out of service and the remaining two ponds are placed in service. The ponds that are out of service are allowed to dewater and the solids are dredged into a separate sludge drying bed and air dried. Any drainage from the sludge drying bed is sent to the settling ponds in service. All of the solids recovered from the toxaphene wastewater are retained in the lagoon system or related drying beds; the estimated total accumulation rate of solids is 5 to 10 tons/day (Hicks, 1975).

Wastewater Characteristics

Hicks (1975) has reported that the average influent flow rate to the Hercules' toxaphene wastewater treatment systems at Brunswick, Georgia, is 200 gpm and that the treatment system has a design flow capacity of 300 gpm. Effluent data obtained between April 1974 and March 1975 is presented in Table 2.

Daily samples taken by Hercules between April 1974 and March 1975, when the flow averaged 167 gpm, showed that the treated effluent discharged into the north ditch had the following average characteristics: (a) pH, 6.0; (b) suspended solids, 57 ppm; and (c) toxaphene concentration, 114 ppb (Hicks, 1975). These statistics are shown in Figure 2 and are the most recent information available.

Under the NPDES Permit No. GA 0003735 (NPDES, 1974), Hercules, Inc., issues monthly discharge reports (Outfall No. 001) to the Environmental Protection Agency, Water Enforcement Branch in Atlanta, Georgia. Jett (1975) has reported that the waste in the 001 outfall includes (a) the treated toxaphene waste stream, (b) unprocessed pine stump wash water which has been clarified, and (c) noncontact cooling water. Data taken from monthly discharge reports, presented in Table 3 show the quantity and and quality of the discharged effluent from Outfall No. 001 for the period of June 29 to August 28, 1975. The average daily discharge of toxaphene during this period ranged from 0.045 to 0.35 lb/day.

Table 2. TOXAPHENE WASTEWATER EFFLUENT DATA
HERCULES, INC., BRUNSWICK, GEORGIA

Month	Average treated effluent flow (gpm)	Average of daily pH readings	Average suspended solids (ppm)	Average toxaphene concentration (ppb)
April 1974	-	6.4	-	104
May 1974	181	4.4	-	93
June 1974	181	4.9	-	81
July 1974	-	5.0	-	176
August 1974	181	6.2	-	203
September 1974	194	6.5	83	125
October 1974	181	6.9	71	99
November 1974	167	6.9	81	109
December 1974	139	6.5	71	-
January 1975	153	6.4	47	90
February 1975	146	6.9	32	58
March 1975	167	5.3	12	-
Overall average	167	6.0	57	114

Source: Hicks (1975).

Note: The toxaphene plant was operated continuously from January 1 to February 23, 1975; then on an intermittant schedule (10 days on-stream and 4 days off) commencing February 26, 1975 (Lair and Bruner, 1975).

Table 3. DATA FROM HERCULES' MONTHLY DISCHARGE REPORTS FOR NPDES PERMIT NO. GA 0003735 AT BRUNSWICK, GEORGIA, PLANT--JUNE 29 TO AUGUST 28, 1975 (Outfall No. 001)

Reporting period:			June 29-July 28, 1975			July 29-August 28, 1975		
Parameter	Units		Minimum	Average	Maximum	Minimum	Average	Maximum
Flow	MGD	Reported	-	3.6	-	-	3.6	-
		Permit condition	-	-	-	-	-	-
Toxaphene	Lb/day	Reported	-	0.45	1.06	-	0.35	0.99
		Permit condition	-	-	1.0	-	-	1.0
Suspended solids	Lb/day	Reported	-	422	960	-	405	900
		Permit condition	-	9,000	27,000	-	9,000	27,000
pH		Reported	6.6	7.1	7.5	6.6	7.4	8.1
		Permit condition	6.0	-	9.0	6.0	-	9.0

Further tests during March 3 to March 6, 1975 (Lair, 1975) showed that the effluent into Dupree Creek had a flow of 16.5 million gpd, a pH of 7.5 and a toxaphene concentration of 4 ppb after dilution in the ditches with 16.3 million gallons per day of cooling water.

The Hercules' treatment facilities are reported to have been constructed to reduce the toxaphene content of the plant discharge to less than 1 lb/day (Hicks, 1975). Information provided in the NPDES permit application for the Brunswick plant (NPDES for Permit No. GA 0003735, 1974) indicate that the effluent from the treatment facility has averaged 0.51 lb/day of toxaphene, but the mean toxaphene content of the total plant discharge (Outfall No. 001) has been about 2 lb/day. Hercules states that "the discrepancy is believed to be due in part to runoff from contaminated areas outside the collection system and problems in sampling and analysis. Efforts are being made to minimize the discrepancy and to reduce the toxaphene content of the total plant discharge" (NPDES, 1974).

The concentration of suspended solids in the effluent discharged from the Hercules' neutralization process (see Figure 2) is unknown and no information on this subject could be obtained from the company. On the basis of the data shown in Figure 2, the loading of suspended solids can be estimated as follows.

Given: Wastewater from neutralization process has a flow rate of 140 gpm which is equivalent to 1,683,000 lb/day (Hicks, 1975). Average daily generations of waste sludge is 7.5 tons or 15,000 lb/day (Ferguson and Mumma, 1975)--all derived from solids contained in neutralization wastewater.

Hicks (1975) has reported that the average concentration of suspended solids in the treated toxaphene effluent (discharged to north ditch) during the period of September 1974 to March 1975 was:

$$57 \text{ ppm or } \frac{1,683,000}{10^6} \times 57 = 96 \text{ lb/day}$$

Then, estimated concentrations of suspended solids in effluent from neutralization process is:

$$\frac{15,000 + 96}{1,683,000 \times 10^{-6}} = \sim 9,000 \text{ ppm suspended solids in effluent from neutralization process}$$

The estimated values developed above are included in Figure 2, the schematic for Hercules' toxaphene wastewater treatment system at Brunswick, Georgia.

Sludge Characteristics

In the Hercules' toxaphene wastewater treatment system, a significant amount (average of 7.5 tons/day) of waste sludge or settled solids is generated (Ferguson and Mumma, 1975). However, no information was obtained from Hercules concerning the toxaphene content in the waste sludge.

On the basis of the available data, shown in Table 2, the approximate toxaphene content in this sludge can be estimated as follows:

Given: Wastewater from neutralization process has a flow rate of 140 gpm and contains ~ 2,200 ppb toxaphene. Treated effluent has a flow rate of 169 gpm and contains 114 ppb toxaphene.

For neutralization wastewater:

$$\text{Flow} = 140 \times 60 \times 24 = 201{,}600 \text{ gpd or}$$

$$201{,}600 \times 8.35 \text{ lb/gal} = 1{,}683{,}000 \text{ lb/day}$$

$$\frac{2{,}200 \text{ ppb} \times 1{,}683{,}000}{10^9} = \sim 3.7 \text{ lb toxaphene/day in wastewater}$$

For treated effluent (discharged to north ditch):

$$\text{Flow} = 167 \times 60 \times 24 = 240{,}000 \text{ gpd or}$$

$$240{,}000 \times 8.35 \text{ lb/gal} = 2{,}000{,}000 \text{ lb/day}$$

$$\frac{114 \text{ ppb} \times 2{,}000{,}000}{10^9} = \sim 0.23 \text{ lb toxaphene/day}$$

For waste sludge (7.5 tons/day),

The toxaphene content is estimated to be:

$$\frac{(3.7 - 0.23)}{7.5 \times 2{,}000} \times 100 = \sim 0.02\% \text{ toxaphene in sludge}$$

In-Plant Controls

The toxaphene production area at Hercules is diked so that all liquid wastes (e.g., leaks or spills) are contained and are eventually processed through the wastewater treatment system. All liquid wastes from the toxaphene unit go to a large holding pond and waste treatment system (Ferguson and Meiners, 1974).

At Hercules, process vents are water, caustic, or lye scrubbed before venting to the atmosphere; waste from these scrubbers also goes to the holding pond. Baghouses are used in the dust concentrate unit, which is located in the toxaphene production area. Dust from the collection system is recycled. Short scheduled shutdowns for maintenance are made as needed (Ferguson and Meiners, 1974).

The tank cars, whether owned by the company or by the railroad, are dedicated to toxaphene and are cleaned yearly at the Hercules plant, with the washings going to the toxaphene recycle system and aqueous wastes through the waste treatment systems. Tank trucks are customer- or truck line-owned and are cleaned by the owner (Ferguson and Meiners, 1974).

Effluent Disposal Method

As shown in Figure 2, effluent from the toxaphene wastewater treatment system is discharged to the north ditch along with cooling waters from the Hercules plant. Effluent from the Hercules' milling area and powerhouse wastewater treatment system is discharged along with plant cooling waters to the south ditch. The outflow from these two ditches is joined into a common plant discharge (Outfall No. 001) which enters Dupree Creek.

The final disposal of treated toxaphene wastewater into municipal sewage treatment plants is an option which may be useful in some locations. Hercules has plans to verify the efficacy of this procedure by plant-scale trials at the Brunswick, Georgia, municipal sewage treatment facility. Hercules has funded a research study on the effect of toxaphene on sewage treatment (Black et al., 1971); the report shows that toxaphene can be added to a sewage treatment plant without adverse effects upon normal treatment processes.

Plant Visit

On August 20, 1975, T. L. Ferguson and C. E. Mumma visited the chemical plant of Hercules, Inc., at Brunswick, Georgia, to discuss toxaphene wastewater treatment. The toxaphene wastewater treatment facilities were examined during this visit (Ferguson and Mumma, 1975).

TENNECO CHEMICALS, INC.

General

The Fords New Jersey Plant, of the Organics and Polymers Division, of Tenneco Chemicals, has its origin in the early 1900's. Since that time, it has changed hands and changed names several times.

In 1963, following a series of mergers with Newport Chemical Company and Nuodex the total assets were acquired by Tennessee Gas Transmission Company. In 1965, the name of Tenneco Chemicals was born.

At present, more than 40 chemicals are produced at Fords. Some of the items are bulk chemicals and are produced at rates of 200 million pounds per year. Some are produced at rates of only 200 pounds per day. The final uses for these chemicals vary from flame retardants for children's sleepwear and intermediates for the paint, dye and plastics industry to food preservatives, agricultural sprays and materials for the cosmetic industry. The current product line (SIC 2818) includes chlorinated aromatics and air oxidation products.

Toxaphene is produced, but is not formulated (Meiners and Mumma, 1975a). The toxaphene products at the Fords plant have the Tenneco trade names of

Strobane® T-90 (90% active ingredient) and Strobane®-T (100% active ingredient). Product quantities are considered by Tenneco to be proprietary information and actual production data were not obtained from the company. On the basis of a communication with a Tenneco representative, the estimated annual production of toxaphene at the Fords, New Jersey, plant is about 9 to 11 million pounds per year (Meiners and Mumma, 1975a). The process equipment which is dedicated to production of toxaphene has been operated since 1965; major revisions were made to the plant in 1969. Tenneco operates the toxaphene plant at least 10 months each year.

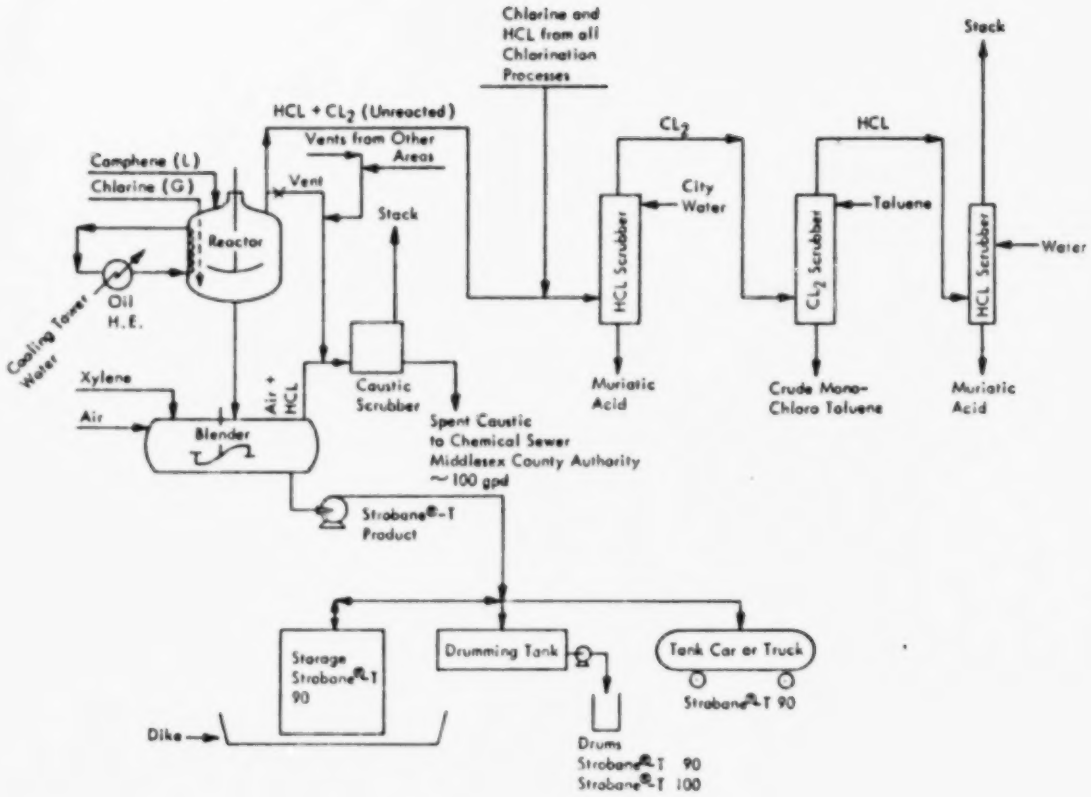
Manufacturing Process (Worley, 1975)

The toxaphene manufacturing unit is part of a chlorination complex in which several processes are integrated by sharing parts of a larger equipment train.

All plant chlorination processes receive chlorine from a common tank car storage-feed system. In addition, all of the processes also direct by-product HCl off-gas to a centrally located acid plant for eventual recovery.

A process schematic for production of Strobane®-T at the Ford's plant is shown in Figure 3. Points where common ties to other processes are made are indicated in this figure.

Strobane®-T is manufactured by a batch process in which chlorine gas is reacted with a camphene liquid to form a waxy solid containing 67 to 69% chlorine content. The camphene is purchased.



Source: Tenneco Chemicals, Letter from J. W. Worley, Works Manager to Mr. W. J. Hunt, Effluent Guidelines Division, EPA, August 13, 1975.

Figure 3. Schematic flow diagram--manufacture of toxaphene (Strobane®-T) by Tenneco Chemicals, Fords, New Jersey

The chlorination reaction is exothermic. Noncontact cooling is provided with an intermediate oil medium, which in turn is water-cooled in a noncontact heat exchanger.

The chlorination by-product HCl and unreacted chlorine gas are vented from the reactor to an acid plant by an off-gas header, which also receives chlorine and HCl from other processes. Both of these off-gases are recovered as by-products by means of gas scrubbers.

When chlorination is completed, the batch is dropped from the reactor to a blend tank where further physical processing occurs. The residual entrapped gases (of HCl and chlorine) are air-sparged for removal. These gases are subsequently neutralized in a common caustic scrubber which is also used for treatment of gases from other (unrelated) operations in the same plant. All of the reactor contents are collected as the final product. By-product muriatic acid (20° Bé) is sold as commercial product. Crude monochlorotoluene, a by-product of other operations, is also recovered and is consumed internally as an intermediate for other chlorine derivatives.

For the preparation of Strobane®-T-90, xylene is added as a diluent to Strobane®-T in a blending operation. Vent gases from the blender, consisting of air and HCl, are scrubbed by contact with a caustic solution. The scrubbed gas is discharged to a vent stack and the spent caustic liquor (~ 100 gpd) is discharged to a chemical sewer.

The product is drummed, charged into tank cars or tank trucks, or placed in storage tanks. The storage tank areas are diked to contain any spilled or leaked material. About 20% of the product is shipped in 50-gal. drums and the balance is usually shipped in railroad tank cars. Tank trucks are used occasionally to ship product.

Tenneco uses a "dry" production process. The process does not use any contact process water and does not have any washing step. Any water in the vicinity of the manufacturing process equipment does not come in contact with the toxaphene itself which is a "bottoms" product. No distillation operations are conducted.

The primary source of noncontact cooling water is a natural ground-fed stream within the plant boundary. This stream is impounded in a man-made pond which overflows to the Raritan River at an approximate rate of 500,000 gal/day (NPDES, 1972). The pond serves as an evaporation heat sink as the noncontact cooling water is drawn from and returned to this pond at a maximum rate of approximately 3,600 gal/min.

The water used for processing is obtained from the Middlesex Water Company of Edison, New Jersey. Water usage in the toxaphene production unit includes makeup water in the cooling water system and water supplied to the caustic scrubber system which treats vent gases.

Wastewater Characteristics (Worley, 1975)

A representative of Tenneco, Inc. (Worley, 1975), has indicated that there is no process wastewater from the Strobane®-T process.

Process wastewaters from all plant processes are collected and directed to common sewer headers which, in turn, flow to a centrally located in-plant collection sump. These wastes are then neutralized with lime and subsequently discharged to the Middlesex County Sewerage Authority (MCSA). These wastes are then collectively analyzed by the MCSA for the parameters of flow gallons, BOD, suspended solids, and chlorine demand.

The "commingled" waste stream (labeled Stream 003) has an average analysis as follows (Worley, 1975):

Flow	million gal/day	1.01
BOD	mg/liter	1,153
S.S.	mg/liter	382
Chlorine demand	mg/liter	8.89

Runoff water flows to either of two discharge streams labeled 001 and 002 located at opposite ends of the plant. Stream 001 includes both ground-fed water as well as natural runoff. Stream 002 contains runoff water only, and its average flow rate is approximately 30,000 gpd. The flow rate of both of these streams vary, depending on the amount of rainfall.

Discharge streams 001 and 002 are covered by the current NPDES Permit No. N.J. 0000116 (1972). The NPDES permit describes the discharge to the Raritan River. Both Streams 001 and 002 have been checked for toxaphene analyses and the results were negative. Therefore, it appears that fugitive losses to the effluent streams are extremely low, if any. The NPDES

Permit Application No. 2SDOXW2000021 (NPDES, 1972) contains information concerning Stream 003. However, Stream 003 is not included in the NPDES permits because the discharge does not flow to a navigable waterway.

The Middlesex Authority provides a monthly composite sample of the total Tenneco plant waste effluent, discharge Stream 003. This composite represents 20 or more individual samples taken by the MCSA as part of their waste monitoring program.

The monthly composite sample is then sent to an outside concern for their individual analysis for toxaphene content.

A recent history of toxaphene analysis in the total Tenneco plant waste discharge (Stream 003) is presented below.

Monthly Composite	Toxaphene Analyses	Monthly Composite	Toxaphene Analysis
May 1974	< 5.0 ppb	November 1974*	-
June 1974	< 10.0 ppb	December 1974*	-
July 1974	< 5.0 ppb	January 1975	< 10 ppb
August 1974	< 5.0 ppb	February 1975	< 5 ppb
September 1974	< 5.0 ppb	March 1975*	-
October 1974	< 5.0 ppb	April 1975	< 5 ppb

* Samples were not sent out for analyses during these months.
Source: Worley (1975).

These data show that the toxaphene content in the wastewater was always less than 10 ppb and usually less than 5 ppb. The monthly average toxaphene content was less than 6 ppb. Tenneco representatives have pointed out that the analyses represented the limit of detectability and that it is possible that there was no toxaphene in the discharge stream. The analytical

samples included suspended solids, since there is no settling of solids prior to discharge.

Spent caustic is discharged at a rate of about 100 gpd from the caustic scrubber unit used in the toxaphene process. No data are available on the composition of this caustic liquor, but Tenneco representatives have indicated that this stream contains little or no toxaphene (Meiners and Mumma, 1975a).

In-Plant Controls

In-plant pollution controls include the noncontact heat exchange used in the toxaphene process and the use of xylene instead of water to clean out the equipment. The xylene cleaning liquor is recovered and used in the plant.

In the event of on-site product spills, the spill is cleaned up immediately and the incident is reported to the state office of EPA.

A water cooling tower is used in conjunction with the noncontact heat exchange system (see Figure 3) to conserve water and permit water recycling.

Containment dikes are provided in the toxaphene production area and around the product storage tanks to prevent loss of pesticide to the environment. All exhaust gases from processing are treated in gas scrubbers before being vented to the atmosphere.

Wastewater Treatment

No wastewater treatment methods are used by Tenneco for the toxaphene manufacturing operation since no wastewater is discharged from the process.

For the total plant effluent, the type of waste treatment employed consists of segregation of streams, collection, neutralization with lime, and discharge (without settling) to the Middlesex County Sewage Authority (Stream 003). The solids generated are discharged along with the effluent stream; no sludge is accumulated.

The Tenneco waste treatment system is designed for a flow of 2 million gallons per day. The annual operating cost is approximately $240,000 which includes the MCSA treatment costs of $100,000/year. The capital value is approximately $290,000, which includes the most recent upgrading expenditure of $85,000 in 1968. The waste treatment system was originally built in 1958 (Worley, 1975).

Plant Visit

On October 13, 1975, Dr. A. F. Meiners and Mr. C. E. Mumma of MRI visited the toxaphene plant site of Tenneco Chemical, Inc., in Fords, New Jersey. Mr. Stephen J. Jelich, Technical Superintendant, and Mr. W. P. Anderson, Director of Environmental Sciences, were interviewed concerning the toxaphene operations. The manufacturing process and waste treatment facilities were examined during the visit (Meiners and Mumma, 1975a).

RIVERSIDE CHEMICAL COMPANY

General

The original chemical plant at Groves, Texas, was built by Sonford Products Company under government contract for production of chlorinated benzene. Later the plant was used to produce chlorinated phenols. Beginning

about 1967, the plant was used to manufacture toxaphene (Meiners and Mumma, 1975b). It was later assumed and operated by Bison Chemical Company.

On February 5, 1974, this plant was purchased from Bison by Riverside Chemical Company, a subsidiary of Cook Industries, Inc. This company is now in the process of extensive renewal and modernization of the entire production facility, including precautions to prevent accidental discharge of toxaphene.

The Riverside Chemical Company's toxaphene plant at Port Neches, Texas, currently produces about 8 to 10 million pounds per year of toxaphene (the address of the plant is a post office box in Groves, Texas). The production capacity of this toxaphene plant has recently been increased and is now about 12 to 14 million pounds per year. The company also produces chlorinated paraffins (about 6 to 7 million pounds per year) at this plant. Hydrochloric acid, a by-product of these chlorination processes, is also recovered and sold. The plant operates 24 hr/day, 7 days/week (Meiners and Mumma, 1975b).

Manufacturing Process

No detailed information on the process technology was obtained (or requested) by project investigators (Meiners and Mumma, 1975b).

Basically, the process consists of reacting chlorine gas with camphene (maximum chlorination temperature is 350°F) and separating out the by-product HCl and excess chlorine in an off-gas stream which is scrubbed to

recover the by-product acid. Heat generated in the exothermic chlorination reaction is removed by noncontact heat exchangers using cooling water. A cooling water tower is provided. Cooling water is recirculated to the toxaphene plant heat exchanger from this cooling water tower. The by-products of the toxaphene process are hydrochloric acid and probably sodium chlorite from the scrubbers (Meiners and Mumma, 1975b).

Well water is used in the toxaphene plant. About 9,500 gpd are consumed in the toxaphene process. In the recovery process for by-product hydrochloric acid (muriatic acid), 3,500 gpd of water are used. The hydrochloric acid process produces 3,000 gpd of product (NPDES, TX0062448, 1975).

Wastewater Characteristics

According to their NPDES Permit No. TX0062448 (NPDES, 1975), the company has the effluent limitations shown below.

EFFLUENT LIMITATIONS
RIVERSIDE CHEMICAL COMPANY TOXAPHENE PLANT
GROVES, TEXAS

Effluent Characteristic	Discharge Limitations kg/day (lb/day) Daily Average	Daily Maximum
Toxaphene	0.02 (0.04)	0.03 (0.06)
Biochemical Oxygen Demand (5 day)	4.5 (10)	9 (20)
Chemical Oxygen Demand	27 (60)	45 (100)
Total Suspended Solids	4.5 (10)	9 (20)
Oil and Grease	2 (5)	NA

Source: NPDES (1975)

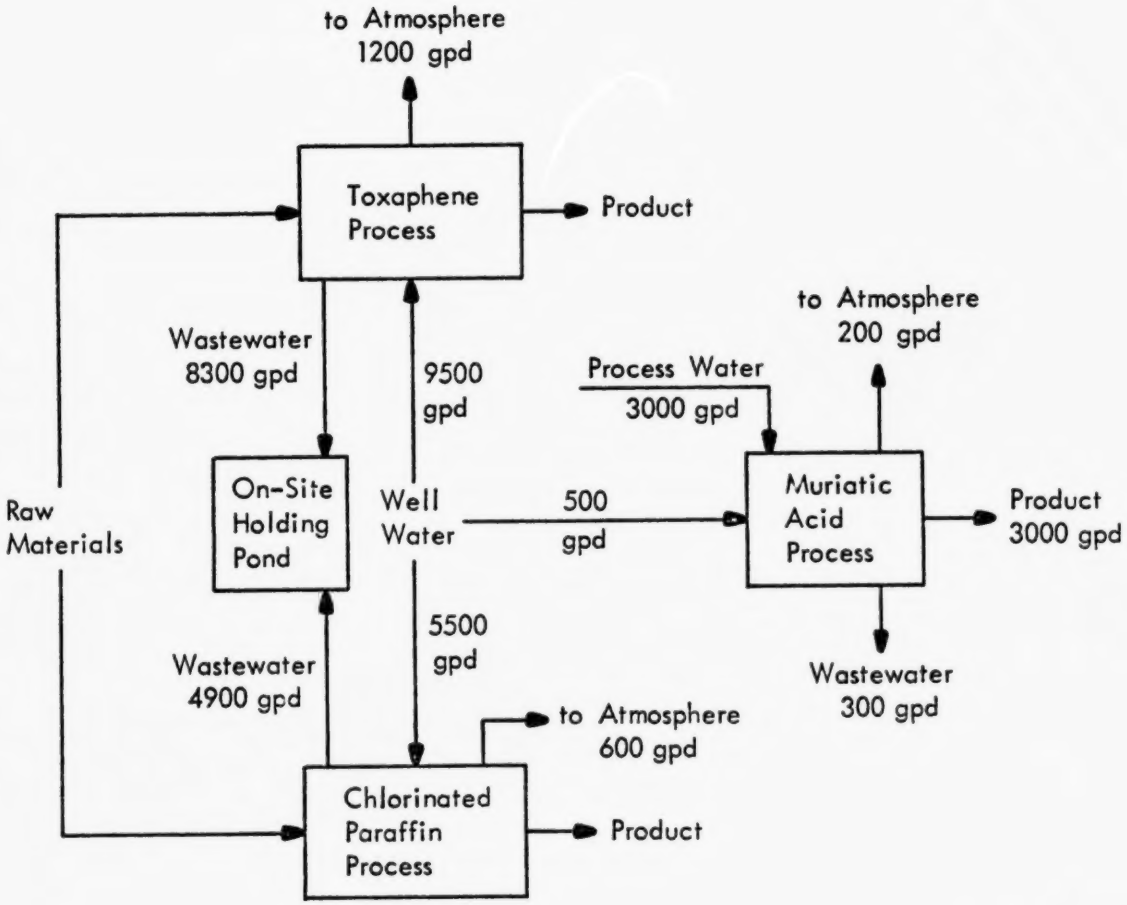
In addition, the permit specifies a 3.0 mg/liter (as CCl_4) discharge of chlorinated hydrocarbons.

According to the NPDES permit (NPDES, 1975) the plant intake of water is 19,000 gpd. This amount of water is accounted for as follows:

Discharges (gpd)	
Surface Water	2,000
Sanitary Water	500
Evaporation	2,000
Consumption	3,000
Boiler and Cooling Tower Blow Down and Condensate	11,500
Total	19,000

In their NPDES permit (NPDES, 1975), Riverside Chemical Company presented a schematic of water flow as shown in Figure 4. Well water is employed in three processes: (a) 9,500 gpd is used in the toxaphene process; of this, 1,200 gpd is evaporated to the atmosphere, and 8,300 gpd is wastewater which is conducted to a holding pond; (b) 5,500 gpd of well water is used in the paraffin chlorination process; 600 gpd is evaporated to the atmosphere; 4,900 gpd is wastewater which is also conducted to the holding pond; (c) 500 gpd of well water and 3,000 gpd of process water are employed in the hydrochloric acid process which produces 3,000 gpd of product and 300 gpd of wastewater. The total indicated amount of wastewater from the three processes is 13,500 gpd. This plant currently generates 12,000 gpd of wastewater (Meiners and Mumma, 1975b).

The by-product hydrochloric acid is sold to Reagent Chemicals Company which is located near the Riverside plant (Meiners and Mumma, 1975b).



Adapted from information provided by Riverside Chemical Company
Source: NPDES Permit No. TX 0062448 (1975)

Figure 4. Schematic of water flow--Riverside Chemical Company, Port Neches, Texas

Analytical data concerning any contaminants in this by-product, hydrochloric acid, were not obtained by project investigators. However, a Riverside Chemical Company official has indicated that there is little, if any, toxaphene contained in this acid (Meiners and Mumma, 1975b).

In-Plant Controls

For in-plant toxaphene operations, pollution control is accomplished by dikes around all process equipment to contain all spills and leaks. A pit is provided for containment of massive spills. Also, a drainage system and collection sump for rainwater runoff has been provided; runoff collected in the sump is pumped to an unlined holding pond. Riverside has had the soil near this pond analyzed for porosity and had found that the soil is nearly impervious to transfer by seepage (Meiners and Mumma, 1975b).

The off-gases from production of by-product hydrochloric acid are neutralized in a gas scrubber before being vented to the atmosphere. At present, there is a small discharge flow (~ 12,000 gpd, see below) from the plant holding pond overflow, cooling tower blowdown, and boiler blowdown to the Jefferson County canal which adjoins the property. In addition, the neutralized caustic solution used to adsorb fugitive hydrogen chloride and chlorine gases from the scrubber goes into the Jefferson County Canal.

Wastewater Treatment

At present, no wastewater treatment method is used by Riverside Chemical Company at their Port Neches, Texas, plant. All wastewater from the diked chlorinating area is collected in a common holding pond (about

75 ft x 150 ft x 10 ft deep) located on-site (see Figure 4). Riverside is meeting the NPDES discharge limitation of 0.04 lb/day of toxaphene (daily average). The average daily volume of wastewater from three processes operated on-site is 12,000 gpd.

A Riverside official has stated that, theoretically, "no discharge" could be achieved. However, in ordinary plant operations, some water discharge will inevitably be required. The "no discharge" achievement would mean that all leaks can be controlled; all by-product hydrochloric acid is sold and the fugitive hydrogen chloride and chlorine gases from the scrubber converted into bleach (Meiners and Mumma, 1975b).

Plant Visit

On August 7, 1975, Dr. A. F. Meiners and Mr. C. E. Mumma visited the toxaphene plant of the Riverside Chemical Company at Port Neches, Texas. Toxaphene production was discussed with Mr. Robert C. Harnden, Senior Vice-President of Riverside Chemical Company. The manufacturing process and waste treatment facilities were examined during this visit.

VICKSBURG CHEMICAL COMPANY

General

The Vicksburg Chemical Company plant at Vicksburg, Mississippi, manufactures organic and inorganic chemicals including toxaphene, potassium nitrate, ammonium nitrate, dinitrobutylphenol (DNBP), methyl parathion, substituted triazines, nitric acid, and chlorine.

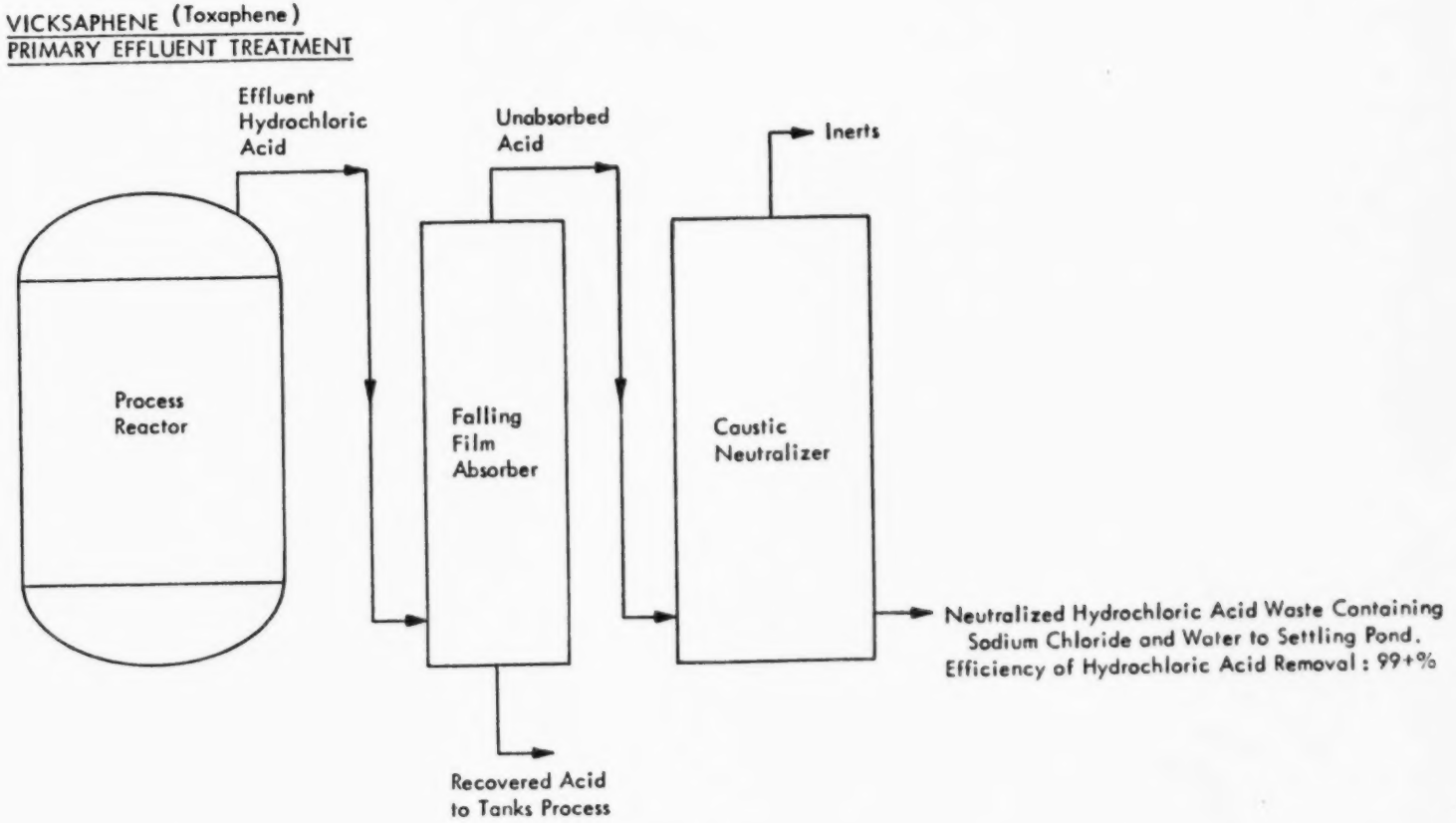
The toxaphene production unit is about 2 years old; the process equipment in this unit is used only for toxaphene manufacture. No toxaphene formulation operations are conducted at this plant. Production of this pesticide product (Vicksaphene®) is carried out on a seasonal basis according to market demand (Meiners and Mumma, 1975c).

Manufacturing Process

A batch type production process is used as shown in Figure 5. Purchased camphene is reacted with chlorine gas; the chlorination is conducted using four reactors connected in series. Chlorine is introduced into these reactors from a vaporizer. The exothermic heat of reaction is removed by noncontact heat exchangers. No solvents are used in the process, but the toxaphene is diluted with 10% xylene and sold as a 90% product.

Effluent hydrogen chloride gas is passed through a falling film absorber, and recovered by-product hydrochloric acid is removed from the bottom of the absorber and sent to storage. All of the by-product acid produced in this process is sold. Data obtained from the State of Mississippi (NPDES Application No. MS0027995, 1975) shows that the daily production of acid amounts to 48,000 lb/day during operating periods.

Off-gases leaving the acid absorber are contacted in a gas scrubber with caustic soda solution to neutralize any unabsorbed HCl or chlorine. Tne scrubbed gas is then vented to the atmosphere. Neutralized HCl waste (containing water and sodium chloride) is discharged at a flow rate of about 10 gpm to a settling pond.


VICKSAPHENE (Toxaphene)
PRIMARY EFFLUENT TREATMENT
Effluent Hydrochloric Acid
Unabsorbed Acid
Inerts
Process Reactor
Falling Film Absorber
Caustic Neutralizer
Neutralized Hydrochloric Acid Waste Containing Sodium Chloride and Water to Settling Pond. Efficiency of Hydrochloric Acid Removal : 99+%
Recovered Acid to Tanks Process

Source: Vicksburg Chemical Company, Fact Sheet, Application for National Pollutant Discharge Elimination System Permit to Discharge Wastewater to Waters of the State of Mississippi, February 25, 1975.

Figure 5. Toxaphene production schematic--Vicksburg Chemical Company, Vicksburg, Mississippi

During the seasonal operating periods, the process is operated 24 hr/day.

Wastewater Characteristics

The only liquid waste produced in the toxaphene process at the Vicksburg, Mississippi, plant is the neutralized HCl waste discharged at a rate of about 10 gpm from the caustic scrubber (Meiners and Mumma, 1975c). Chemical analyses performed by independent testing laboratories on samples of this effluent have not detected any toxaphene. (The analytical methods used were not stated.)

An engineering report was recently prepared for the Vicksburg Chemical Company by Enviro-Labs, Inc. (Enviro-Labs, 1975) as part of the requirement for the NPDES permit. The information concerning toxaphene in this report is quoted below.

"Toxaphene produces no liquid wastewater; however, there is a scrubber of high pH content to remove any chlorine that may escape from the reactor. The flow rate from the scrubber is approximately 10 gpm."

In-Plant Controls

The use of a noncontact cooling procedure for the chlorination reaction serves to reduce greatly the quantity of wastewater.

The entire toxaphene production facility is built on a concrete pad and is diked to contain any spills, leaks and rainwater runoff in the production area.

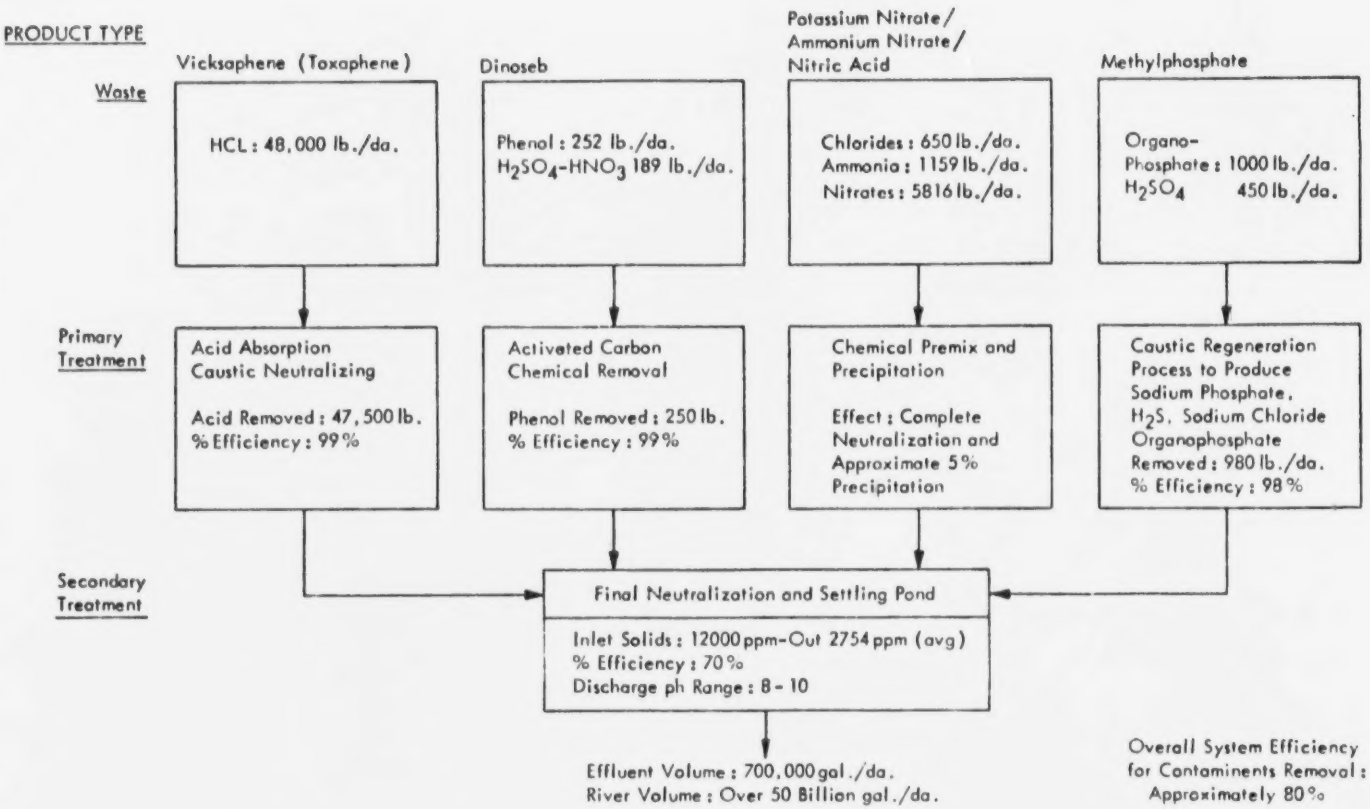
Wastewater Treatment

The only effluent from the toxaphene process is spent caustic solution discharged from the off-gas scrubber at a rate of approximately 10 gpm (Enviro-Labs, 1975). A Vicksburg Chemical Company official has stated that independent analysis of this effluent has failed to detect the presence of toxaphene (Meiners and Mumma, 1975c). This effluent is discharged to a final neutralization and settling pond located on-site as shown in Figure 6. Waste liquor is pumped from this pond to the city treatment plant (Figure 7).

A Vicksburg Chemical Company official has pointed out that zero discharge of effluent is not considered to be feasible, since it is probably impossible to avoid the small discharge (10 gpm) of effluent from the off-gas caustic scrubber (Meiners and Mumma, 1975c).

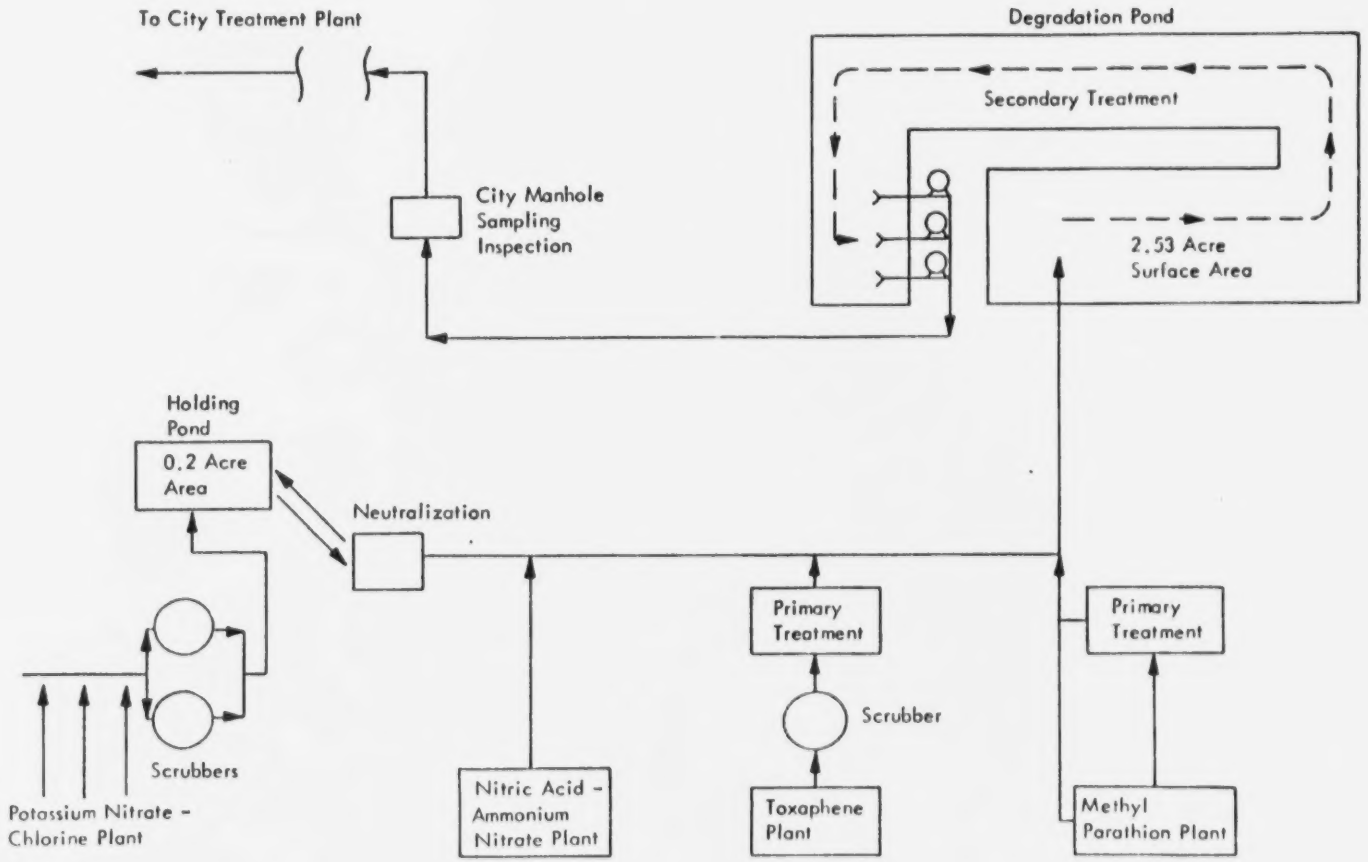
Plant Visit

On October 14, 1975, A. F. Meiners and C. E. Mumma visited the production plant of the Vicksburg Chemical Company in Vicksburg, Mississippi. Toxaphene production was discussed with Mr. Silvan B. Lutkewitte, President, and Mr. Jerry W. McAdams, Environmental Engineer. The manufacturing process and waste treatment facilities were examined during this visit.



Source: Vicksburg Chemical Company, Fact Sheet, Application for National Pollutant Discharge Elimination System Permit to Discharge Wastewater to Waters of the State of Mississippi, February 25, 1975

Figure 6. Effluent treatment process--Vicksburg Chemical Company, Vicksburg, Mississippi



Source: Vicksburg Chemical Company, Fact Sheet, Application for National Pollutant Discharge Elimination System Permit to Discharge Wastewater to Waters of the State of Mississippi, February 25, 1975

Figure 7. Liquid waste disposal system--Vicksburg Chemical Company, Vicksburg, Mississippi

SECTION III

ALTERNATE SYSTEMS FOR REMOVING TOXAPHENE FROM WASTEWATER

A number of wastewater treatment methods have been investigated for the removal of toxaphene from wastewater. The methods which have received the most attention in past and current research, and which appear to be the most promising are (a) adsorption on synthetic resins, (b) reductive degradation, and (c) carbon adsorption. None of these systems have been operated under conditions which approximate actual use for toxaphene removal, nor have they been developed to a point where an accurate determination of operating conditions or costs can be made with confidence. In this section of the report, each of these systems is described, the probable effluent quality which can be achieved by each system is estimated, and the cost of each system is estimated based on its application to the toxaphene wastewater generated at the Hercules plant.

PRESENT STATUS OF ALTERNATE SYSTEMS FOR TREATING TOXAPHENE WASTEWATERS

Presented below are brief discussions of the present status of alternate systems for the treatment of toxaphene wastewater.

Adsorption on Synthetic Resin

The Rohm and Haas Company has developed a synthetic, polymeric adsorbent which shows excellent promise for the removal of pesticides from wastewater. According to this process, pesticides are adsorbed on Amberlite XAD-4, a synthetic, polymeric adsorbent processing high porosity (0.50 to 0.55 ml of pore per milliliter of bead), high surface area (850 m^2/g) and an inert, hydrophobic surface (Kennedy, 1973). The adsorbent is regenerated with an organic solvent, and the adsorbed pesticides are recovered in a concentrated form.

The process appears to have important advantages over carbon adsorptions. For example, the XAD-4 resin has been shown to be superior to activated carbon both in terms of pesticide leakage and in overall operating capacity (Kennedy, 1973).

Although the laboratory data look promising, many problems must be worked out before a practical process can be operational. To the best of our knowledge as of November 18, 1975, pilot-scale tests of the efficiency of treating toxaphene wastewater by this process have not been performed.

Reductive Degradation

Promising laboratory results have been shown by a degradation process involving the catalyzed reduction of chlorinated pesticides to relatively nontoxic products which do not contain chlorine. The process consists of a copper-catalyzed reduction of the pesticide in water by iron. The pesticide containing wastewater is passed through a packed column with the reductant suitably diluted with inert particles to obtain good flow properties.

Sweeny and Fischer (1970) and Sweeny et al. (1973) have reported that this process appears to be attractive for the destruction of a wide range of chlorinated hydrocarbon pesticides, including the cyclodiene pesticides: aldrin, dieldrin, chlordane, endrin and heptachlor. In laboratory studies, the process was found to proceed smoothly at ambient temperatures to remove all or a substantial amount of the chlorine from dissolved pesticides.

Applicability of the technique to toxaphene waste has been reviewed (Ferguson and Meiners, 1974). In one test, toxaphene waste was passed through a column at neutral pH. There was no deviation from the gas chromatograph baseline indicative of any of the seven principal peaks of toxaphene in the effluent (< 0.1 ppb); the solutions before treatment ranged as high as 5.5 mg/liter toxaphene (probably indicating the presence of some suspended toxaphene).

Activated Carbon

Limited laboratory data are available concerning the adsorption of toxaphene on activated carbon.

Hager and Rizzo (1974) have prepared limited isotherm data for the adsorption of toxaphene on carbon. The adsorption isotherm is the relationship, at a given temperature and other conditions, between the amount of a substance adsorbed and its concentration in the surrounding solution. A reading taken at any point on an isotherm gives the amount of material

adsorbed per unit weight of carbon. In very dilute solutions, such as wastewater, a logarithmic isotherm plotting usually yields a straight line.

From adsorption isotherm data, a determination can be made of whether or not a particular degree of organic removal can be effected by adsorption alone. Isotherm data will also show the approximate adsorptive capacity of the carbon for the application. Isotherm data represent a large amount of information condensed into concise form for ready evaluation and interpretation.

The data of Hager and Rizzo (1974) were obtained using granular carbon and toxaphene in distilled water. These studies were performed at toxaphene concentrations between about 11 and 175 ppm.

THE FEASIBILITY OF ALTERNATE SYSTEMS FOR REMOVING TOXAPHENE FROM WASTEWATER

Considerable information is available concerning the treatment of endrin wastewaters by means of reductive degradation and by adsorption on carbon and on Amberlite resin. However, very little information is available concerning the application of these processes to toxaphene. A careful consideration of (a) the available experimental data, (b) the similar chemical and physical properties of the two products, and (c) an evaluation of the opinions of researchers knowledgeable of the processes, leads to the conclusion that these processes should have practical application to toxaphene as well as endrin. These topics are discussed below.

A Comparison of the Chemical and Physical Properties of Endrin and Toxaphene

An examination of the chemical and physical properties of endrin and toxaphene (Table 4) reveals that they are similar in regard to properties that are important to the phenomenon of adsorption, such as affinity for water, polarity, and solubility. The chemical natures of the two pesticides are also similar; both are highly-chlorinated products containing over 56% chlorine by weight. It could be predicted that these products would behave similarly in many chemical reactions, such as oxidation or reduction, and in fact both products have been shown to be resistant to oxidation and susceptible to the reductive degradation reaction.

The resistance of endrin to oxidation is indicated by the experiments of Robeck et al. (1965) which show that highly chlorinated hydrocarbons such as endrin, lindane, and dieldrin, are not further oxidized by chlorine. Robeck et al. (1965) state that "It was not anticipated that chlorination would have much effect on the chlorinated hydrocarbons." Further experimental work is cited by Marks (1974a) which shows that the chemical oxidation of endrin in water by the oxidant potassium permanganate is "ineffective."

The resistance of toxaphene to oxidation is exemplified by the work of Cohen et al. (1960), which showed, that, as expected, toxaphene in water was not affected by chlorine.

The susceptibility of both endrin and toxaphene to reductive degradation is discussed below.

Table 4. CHEMICAL AND PHYSICAL PROPERTIES OF ENDRIN AND TOXAPHENE[a/]

	Endrin	Toxaphene
Chemical Class	Chlorinated hydrocarbon	Chlorinated hydrocarbon
Description	Crystalline solid	Waxy solid
Empirical formula	$C_{12}H_8Cl_6O$	~ $C_{10}H_{10}Cl_8$[b/]
Molecular weight	381	~ 415[b/]
Chlorine content	56%	67-69%
Carbon content	38%	28-31%
Hydrogen content	2%	~ 2.5%
Melting point	> 200°C (with decomposition)	~ 84°C
Affinity for water	Hydrophobic	Hydrophobic
Polarity	Nonpolar	Nonpolar
Flammability	Nonflammable	Nonflammable
Solubility		
Water	Very slightly soluble (0.23 ppm at 25°C)[c/]	Very slightly soluble (0.4-3.0 ppm)[c/]
Petroleum oils	Slightly soluble	Soluble
Acetone	Soluble	Soluble
Benzene	Soluble	Soluble

a/ The information presented in this table was obtained from multiple sources which are in general agreement.

b/ Toxaphene has the approximate composition $C_{10}H_{10}Cl_8$. It consists of a mixture of 20 to 30 major compounds resulting from the chlorination of camphene, but is predominantly a mixture of the octachlorocamphene isomers.

c/ Gunther, F. A., "Reported Solubilities of 738 Pesticide Chemicals in Water," Residue Reviews, 20:1-145 (1968).

Reductive Degradation

Considerable development work has been performed on the reductive degradation process applied to wastewaters containing endrin (Sweeny et al., December 1973; Sweeny, May 1974; Sweeny, September 1974). Relatively little work has been done concerning the application of this process to toxaphene. However, the Envirogenics Company has demonstrated in the laboratory that the reductive degradation system using copper-catalyzed iron can reduce the concentration of toxaphene to less than 3 ppb from a concentration of 1,000 ppb (Sweeny et al., December 1973). Also, Sweeny in a patent owned by the U.S. government (Sweeny, June 1973) describes a series of tests using the process for the reduction of toxaphene, chlordane, dieldrin, aldrin, heptachlor, and polychlorinated polyphenyls. Substantial conversion of these compounds (which are all highly-chlorinated organics) was confirmed by gas chromatography and by chloride ion determinations.

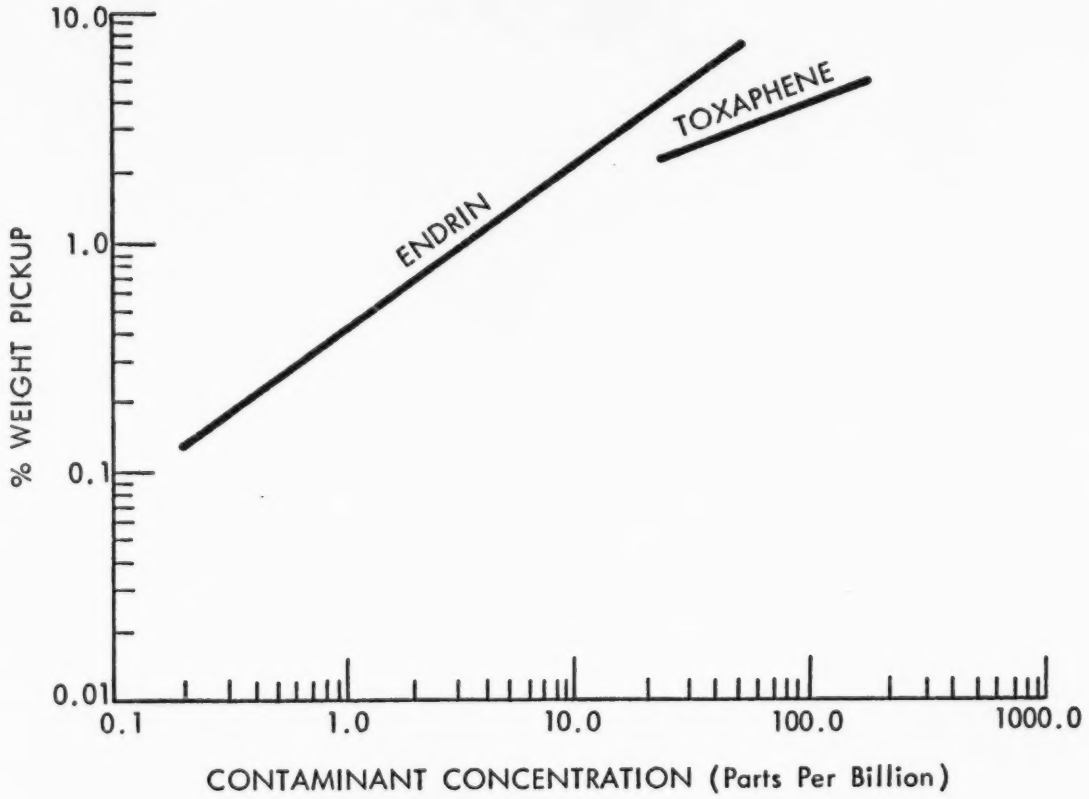
Dr. Robert Swank, Acting Chief, Industrial Pollution Branch, Environmental Protection Agency, Athens, Georgia, is project monitor for the current project study (EPA Contract No. 68-01-0083) involving the reductive degradation of endrin and other highly-chlorinated hydrocarbons. Dr. Swank is convinced that the reductive degradation system would be practical for toxaphene as well as for other chlorinated pesticides (Swank, 1975).

Dr. K. H. Sweeny is program manager for a current study of the application of the reductive degradation system for the removal of chlorinated hydrocarbon pesticides from wastewater (EPA Contract No. 68-01-0083,

Envirogenics Systems Company). Dr. Sweeny believes that the reductive degradation process is very promising for the removal of toxaphene from wastewater (Sweeny, 1975).

Adsorption of Toxaphene on Carbon and on Amberlite Resin

In the candidate systems for resin adsorption and carbon adsorption dilute aqueous solutions of endrin and toxaphene, 300 and 500 ppb, respectively, are contacted with the adsorbent. The phenomenon responsible for the removal of the contaminant from water involves physical adsorption of the contaminant on the surface of the adsorbent. There is strong evidence that carbon will effectively adsorb both of these products. Figure 8 presents the data obtained by the Calgon Corporation (Hager and Rizzo, 1974). This figure shows that carbon is effective in removing both contaminants from water at concentrations of about 20 ppb; the weight pickups are approximately 2% for toxaphene, 3% for endrin. The concentration of endrin can be reduced to about 0.2 ppb. A linear extrapolation of the toxaphene isotherm indicates that the weight percent pickup by carbon would be even greater for toxaphene than for endrin at concentrations below about 5 ppb. The extrapolation of the toxaphene isotherm to lower concentrations is reasonable because, according to the Process Design Manual for Carbon Adsorption published by EPA (Cornell, 1973), "In very dilute solutions, such as wastewater, a logarithmic isotherm plotting usually yields a straight line."



Source: Hager and Rizzo (1974).

Figure 8. Simplified adsorption summary - toxaphene

For several years the Rohm and Haas Company has been investigating the adsorptive properties of its proprietary resin, Amberlite XAD-4, for the removal of contaminants from water. The properties of the resin have been described by Rohm and Haas (Rohm and Haas, 1971). The resin has been shown to be very effective compared to carbon for the removal of "chlorinated pesticides from actual manufacturing waste effluents" (Kennedy, 1973).

In our recent contacts with Rohm and Haas Company, personnel restated the usefulness of the resin for wastewater treatment. Rohm and Haas states that it has evaluated this resin compared to carbon, and that in all tests to date the resin has been superior to carbon in reducing the contaminant concentration (Huritz, 1975). Although Rohm and Haas has not tested its resin on endrin or toxaphene, it has performed confidential studies for various industrial clients; for one "chlorinated pesticide," the wastewater concentration was reduced from 300 to 500 ppb to 1 to 3 ppb (Borenstein, 1975).

Thus, the available evidence indicates that the Amberlite XAD-4 resin would be feasible for use in a practical system for the removal of toxaphene from water.

FLOW DIAGRAMS OF ALTERNATE SYSTEMS FOR REMOVING TOXAPHENE FROM WASTEWATER

Although the alternate treatment systems have been operated on only a laboratory scale, not on a pilot scale, it is possible for the purpose of cost estimation to prepare flow diagrams showing the approximate design of the systems. Also, as pointed out earlier in this section of the report,

the alternate systems would be expected to be approximately as effective in treating toxaphene wastewater as they are in treating endrin wastewater. On this basis, an estimate of effluent quality can be made. Discussed below are (a) flow diagrams of alternate systems for the treatment of toxaphene wastewater and (b) the expected quality of the effluent produced when the alternate systems are used to treat the toxaphene wastewater. The systems are applied to wastes generated at the Hercules, Inc., plant at Brunswick, Georgia, since the other manufacturers produce substantially smaller waste streams.

The Amberlite XAD-4 Resin and Reductive Degradation Systems

The Amberlite XAD-4 resin system and reductive degradation system are being studied for treatment of chlorinated pesticide wastes by Velsicol Chemical Corporation and Envirogenics Systems Company, respectively. Envirogenics has tested the capability of the reductive degradation system to remove toxaphene from wastewater. No information is available on treatment of toxaphene wastes with the resin system. A general description of these systems was presented earlier in this section.

Design flow diagrams of these alternate treatment systems are presented in Figures 9 through 12. In each system, the plant process wastewater containing toxaphene is passed through a sedimentation process and a filtration process (a) to remove the suspended solids that would otherwise pass through the XAD-4 resin system or overburden the reductive degradation system, and (b) to allow destruction of the free chlorine by sunlight (requiring 8 hr of exposure). The figures show the quality of the treated effluent discharged and the sludge disposal operations.

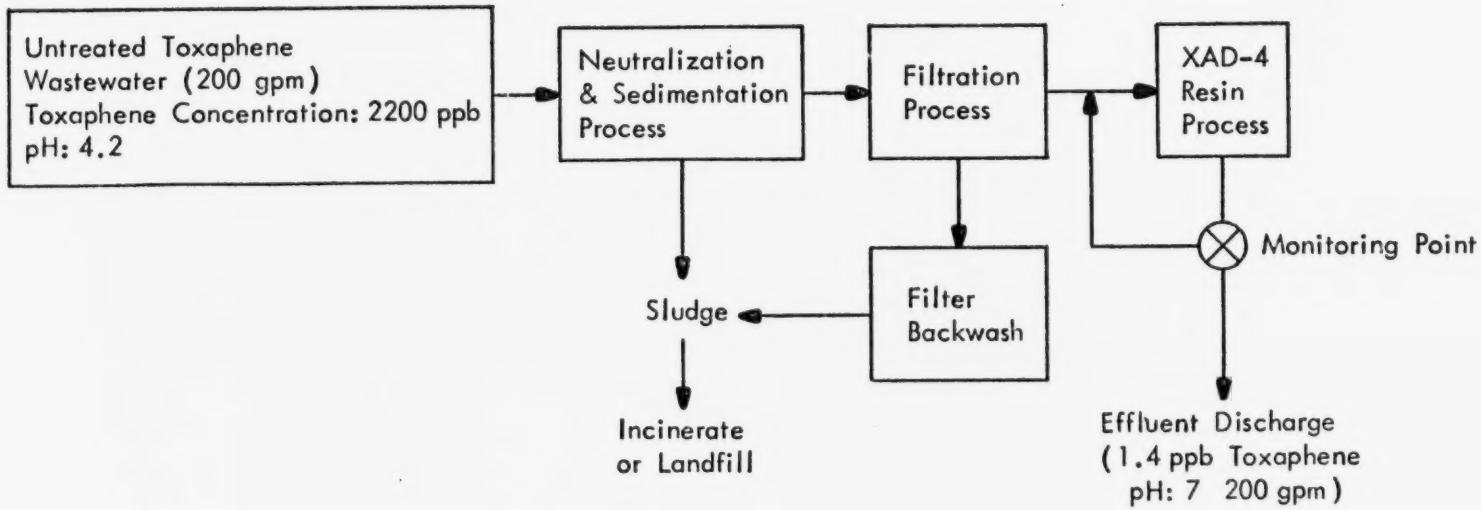


Figure 9. Design flow diagram of Amberlite XAD-4 resin system

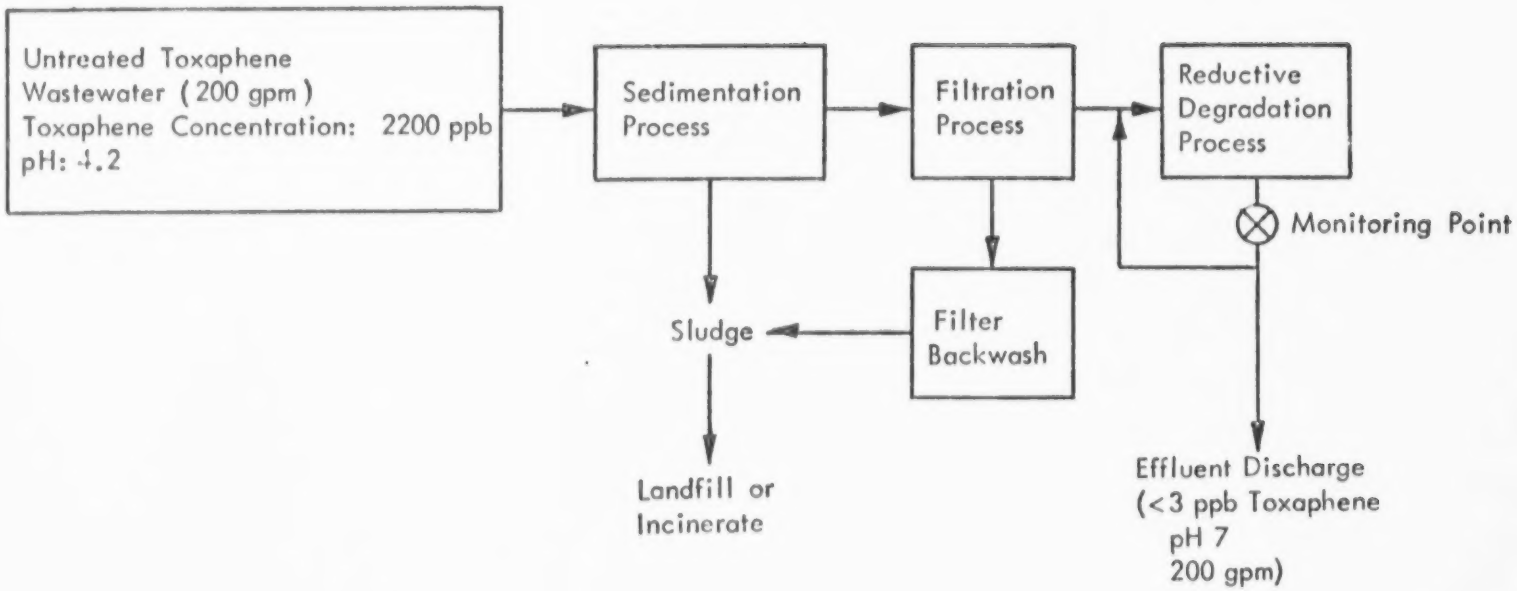


Figure 10. Design flow diagram of reductive degradation system

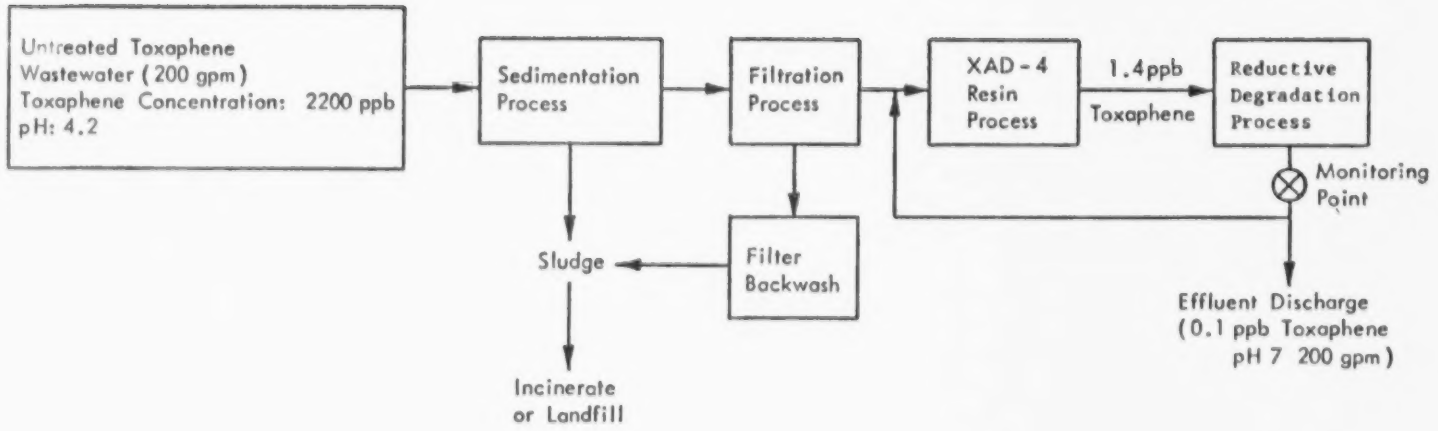


Figure 11. Design flow diagram of Amberlite XAD-4 resin system and reductive degradation system in series

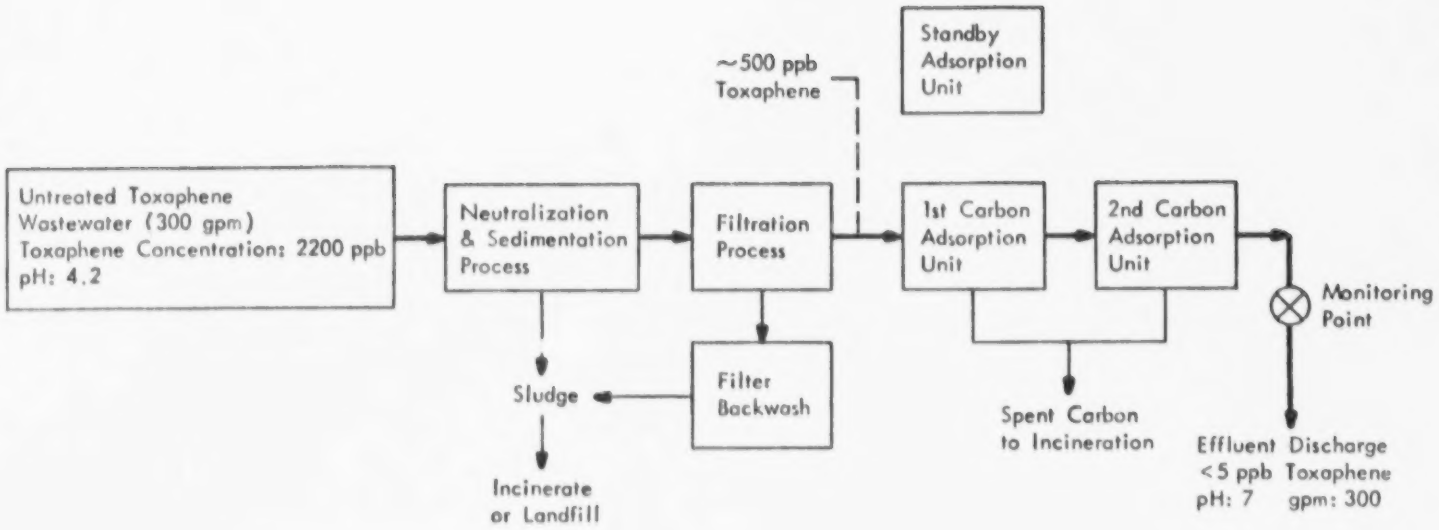


Figure 12. Design flow diagram for a carbon adsorption system

Figure 9 shows the design flow diagram of Amberlite XAD-4 resin adsorbent system. In the XAD-4 system, the wastewater is passed through vertical columns packed with resin that adsorbs the toxaphene. The resin is periodically regenerated by flushing the resin beds with isopropyl alcohol to remove accumulated toxaphene. The treated wastewater passes through a monitoring point and is then discharged.

Figure 10 shows the design flow diagram of the reductive degradation system. The reductive degradation process operates by first neutralizing (to pH 7) the acid wastewater with sodium carbonate in a pH adjustment tank. After neutralization, the wastewater passes through parallel reductant columns that are packed with copper-catalyzed iron and sand. The toxaphene is destroyed by reductive degradation in the columns. Subsequently, the treated wastewater is monitored and discharged.

Figure 11 shows the two systems in series. The wastewater is processed through the XAD-4 resin system, the reductive degradation system, and then discharged.

The process equipment involved in each system is given in greater detail in the cost estimates discussed subsequently.

The Quality of the Treated Effluent

The quality of the toxaphene wastewater after treatment by the reductive degradation system has been determined in laboratory studies conducted by Envirogenics. However, the tests conducted by Velsicol (Marks, March 1974) using the XAD-4 resin system involved only endrin wastewater. The

transfer of endrin treatment technology to treatment of toxaphene wastewater appears to be feasible as discussed earlier in this report. Based upon the information to date, the probable quality of the treated effluent from each of the three systems is as follows.

Amberlite XAD-4 Resin System - Velsicol has demonstrated in the laboratory that the XAD-4 resin adsorbent system can reduce the concentration of endrin in wastewater down to an average of 1.36 ppb (Marks, March 1974). For reasons described earlier in this report, we believe that the resin system would be approximately as effective for toxaphene as it is for endrin.

The Reductive Degradation System - Envirogenics Systems Company has demonstrated in the laboratory that the reductive degradation system using copper-catalyzed iron can reduce the concentration of toxaphene down to less than 3 ppb from a concentration of 1,000 ppb (Sweeny et al., July 1973).

Amberlite XAD-4 Resin System and Reductive Degradation System in Series - This system treats the toxaphene wastewater with the XAD-4 resin system first, and reduces the toxaphene concentration down to about 1.4 ppb prior to treatment by the reductive degradation system. The reductive degradation system has not been tested for treating this low concentration of toxaphene, but it is reasonable to assume a ten-fold decrease in toxaphene levels in this case (since the higher concentration of 1,000 ppb was reduced over 300-fold). Therefore, the amount of toxaphene in the effluent of these two systems acting in series is estimated to be about 0.1 ppb.

Carbon Adsorption System

A conceptual flow diagram for a carbon adsorption process (Hutchins, 1975a) is shown in Figure 12. The portions of this process which deal with removal of suspended solids and pH adjustment in the wastewater are taken to be identical to the process steps of sedimentation, filtration and neutralization, which are used in the reductive degradation system.

After removal of suspended solids from the wastewater, it is conducted through a two-stage carbon adsorption system consisting essentially of (a) two on-stream carbon adsorption units operating in series and one standby adsorption unit packed with granular activated carbon, and (b) the required auxiliary equipment (pump, piping, process instrumentation, etc.).

When the concentration of toxaphene in the effluent from the first unit is equivalent to the feed concentration, the carbon in the unit is exhausted and the unit is taken off stream (Hutchins, 1975a). The second unit then becomes the lead unit and the standby column is put on stream as the second column in the series. The exhausted unit is discharged, refilled with fresh carbon, and used as standby. Because of the small requirement for activated carbon, regeneration of the carbon is not economically justified (Hutchins, 1975b). The exhausted carbon is disposed of by incineration; the costs for incineration are not included in this study.

Robeck (1965) has reported test data (Table 5) for carbon adsorption of endrin from wastewater; the influent contained 10 ppb endrin and the endrin removal was over 99%. Similar results were reported for wastewaters containing other chlorinated hydrocarbon pesticides. In this study, it was considered that a similar adsorption efficiency would apply for toxaphene wastewater; on this basis the estimated endrin content in the treated effluent would be less than 5 ppb.

Table 5. SUMMARY OF CUMULATIVE PESTICIDE REMOVAL AT 10-PPB LOAD

Process	Pesticide removed (%)					
	DDT	Lindane	Parathion	Dieldrin	2,4,5-T Ester	Endrin
Chlorination (5 ppm)	< 10	< 10	75	< 10	< 10	< 10
Coagulation and Filtration	98	< 10	80	55	65	35
Carbon: Slurry						
5 ppm		30	> 99	75	80	80
10 ppm		55	> 99	85	90	90
20 ppm		80	> 99	92	95	94
Carbon: Bed						
0.5 gpm/cu ft	> 99	> 99	> 99	> 99	> 99	> 99

Source: Robeck, 1965 (p. 198).

POSSIBILITIES FOR ZERO DISCHARGE IN TOXAPHENE MANUFACTURE

There is no apparent potential for zero discharge of effluent for the Hercules, Inc., toxaphene wastewater treatment process currently used at the Brunswick, Georgia, plant. Major equipment changes and modifications in the existing treatment facility would be required to even approach a

condition of zero discharge at this site. The presently used treatment process does not appear to be amenable to operation with zero discharge. At present the discharge of wastewater is estimated to be about 3.5 gal/lb of toxaphene product.

According to data obtained during site visits to Tenneco, Inc., at Fords, New Jersey, to Vicksburg Chemical Company, Vicksburg, Mississippi, and to Riverside Chemical, at Groves, Texas, the other three domestic toxaphene plants are in a much more favorable position than Hercules for either closely approaching or achieving a no discharge type of operation. (See references: Meiners and Mumma, 1975a; Meiners and Mumma, 1975b; and Meiners and Mumma, 1975c.) According to data furnished by the producing companies, the Tenneco, Inc., plant and the Vicksburg Chemical Company plant presently have no discharge of process wastewater; both of these plants do have a discharge of caustic waste liquid from off-gas scrubbing operations, i.e., about 100 gpd spent caustic liquid for Tenneco and 14,400 gpd of spent caustic at Vicksburg plant. The Riverside plant currently discharges about 12,000 gpd of toxaphene contaminated wastewaters containing an average of about 0.04 lb of toxaphene (i.e., an average concentration of about 0.4 ppm toxaphene in discharge wastewater).

A plant official at the Riverside Chemical Company has stated (Meiners, August 1975) that "for practical purposes no discharge can be achieved by toxaphene plants." However, this official believes that in ordinary plant operations some water discharge will inevitably be required and that the

no discharge achievement would mean that practically all of the by-product hydrochloric acid from the toxaphene process would be sold as product.

COMPARISON OF EFFLUENTS PRODUCED BY ALTERNATE TREATMENT SYSTEMS WITH EFFLUENT LIMITATIONS GUIDELINES

The Environmental Protection Agency in their "general instructions" to contractors (Part II) describes effluent limitations guidelines in terms of Levels I, II, and III technology. These levels of technology are briefly defined below and replace the terms "best practicable control technology currently available" (BPCTCA), "best available technology economically achievable" (BATEA) and "best available demonstrated control technology" (BADCT).

Level I - Control and Treatment Technology

This level must be achieved by all plants in each industry not later than July 1, 1977. "Level I technology should be based upon the average of the best existing performance by plants of various sizes, ages and unit processes within each industrial category or subcategory. This average shall not be based upon a broad range of plants within an industrial category or subcategory, but shall be based upon performance levels achieved by exemplary plants."

Level II - Control and Treatment Technology

This level is to be achieved not later than July 1, 1983. "Level II technology is not based upon an average of the best performance within an industrial category, but is to be determined by identifying the very best

control and treatment technology employed by a specific point source within the industrial category or subcategory, or where it is readily transferable from one industry process to another, such technology may be identified as Level II technology."

Level III - Control and Treatment Technology

This level is to be achieved by new sources. "Level III technology shall be evaluated by adding to the consideration underlying the identification of Level II technology a determination of what higher levels of pollution control are available through the use of improved production processes and/or treatment techniques."

The effluent limitations tentatively recommended for the "Halogenated Organic Pesticides" subcategory of the "Pesticides and Agricultural Chemicals Industry" category are presented in Table 6.

Except for one plant, the Hercules plant (Brunswick, Georgia), the effluent limitations guidelines cannot be compared with the quality of effluents from toxaphene production units. In general, no data concerning BOD, suspended solids, or phenol concentration are available for the effluent from the toxaphene processes. Although data of this kind are reported for the total plant effluent, the total effluent consists of discharges from a number of other processes.

SECTION IV

WASTEWATER TREATMENT COST ESTIMATES

In this portion of the report, capital investment costs and annual operating costs are estimated (a) for presently used toxaphene wastewater treatment systems and (b) for alternate wastewater treatment systems.

ESTIMATED COST OF PRESENTLY USED WASTEWATER TREATMENT SYSTEMS

Presented below are estimates of the capital investment costs and operating costs for wastewater treatment systems currently in operation at the four toxaphene production plants in the United States.

The Hercules Plant (Brunswick, Georgia)

A description of the wastewater treatment system used at the Hercules plant has been presented in Section III. Lair and Bruner (1975) have reported that the treatment facilities were built by Hercules during the period 1971 to 1974. The design flow capacity of this treatment system is reported to be 300 gpm, and the design toxaphene content in treated effluent is 1 lb/day (Hicks, 1975).

The capital cost of the toxaphene wastewater treatment system is reported by Hicks (1975) to be about $800,000. The annual operating cost of the treatment facility in 1974 was reported to be about $300,000, including

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monitoring costs and technical services (Hicks, 1975). These costs do not include a solid waste disposal procedure.

The Tenneco, Riverside, and Vicksburg Plants

None of these three plants operate a toxaphene wastewater treatment system. Therefore, no treatment cost data are available for these plants. A detailed description of the waste disposal systems used by these plants is presented in Section II.

ESTIMATED COST OF ALTERNATE TOXAPHENE WASTEWATER TREATMENT SYSTEMS

Investment and operating cost estimates have been prepared for four potential alternate systems. The costs have been estimated based upon the application of the treatment systems to the toxaphene wastewater generated at the Hercules plant (Brunswick, Georgia). Costs have been estimated for the following systems: (a) adsorption on synthetic resins, (b) reductive degradation, (c) adsorption on synthetic resins followed by reductive degradation, and (d) adsorption on granular activated carbon.

One alternative, in addition to those above, would be to reduce the wastewater flow rate and quantity. However, no information is available concerning the cost of achieving a reduced wastewater flow; therefore, no cost estimate is made for this alternative.

Cost estimates have been made for two flow rates, 200 gpm and 300 gpm. According to Hicks (1975), the present treatment system has a design flow capacity of 300 gpm and the average influent flow rate is about 200 gpm.

A discussion of the methodology and the results of the cost estimates is presented below.

Estimated Capital Investment Costs for the Resin Adsorption System and the Reductive Degradation System

Information concerning the alternate treatment systems and their associated costs is derived in part from information submitted by Velsicol Chemical Corporation (Marks, September 1974) and in part from reports by Envirogenics Systems Company (Sweeny, May 1974 and September 1974) concerning the pilot plant demonstration units. Where the costs of required process equipment or labor were not stated by the two above companies, these costs are estimated. In addition, the treatment systems are scaled up from the proposed demonstration units (100 gpm flow) to 200 and 300 gpm, and the costs are given in April 1975 dollars.

Since all of the alternate systems require both a sedimentation and filtration process, and the costs of these two processes are identical for each system, these processes are examined first. Following the treatment and filtration processes, each of the alternate systems are discussed separately. The cost estimates for the system are then summarized and totaled.

Sedimentation Process Costs - The sedimentation process will allow large solid undissolved particles to settle out of the wastewater prior to filtration. The installed capital cost for a system to handle 200 gpm (288,000 gpd) and 300 gpm (432,000 gpd) is estimated from a report by Blecker and Nichols (1973). The graph on page 126 of their report shows that the installed cost (1972 dollars) of a sedimentation system to handle 1 million gallons per day is $65,000. The installed costs for the systems to handle 200 and 300 gpm flows are extrapolated from the graph and are

$20,000 and $25,000, respectively. These installed systems for the sedimentation process include the purchased cost of tanks, motors and drives, pumps, piping, concrete, structural steel, instrumentation, electrical, paint, and indirect costs.

Since these installed costs are given in 1972 dollars, the costs must be escalated to April 1975 prices. To do this, the Chemical Engineering (CE) Plant Cost Index is used. Chemical Engineering (1975a) reports that in 1972, this index was 137.2 but had risen to 180.6 by April 1975. Therefore, the estimated installed capital cost (rounded) of each sedimentation process system is:

$$\text{200 gpm process: } (\$20{,}000)\left(\frac{180.6}{137.2}\right) = \$26{,}300$$

$$\text{300 gpm process: } (\$25{,}000)\left(\frac{180.6}{137.2}\right) = \$32{,}900$$

Blecker and Nichols (1973) reported that the annual maintenance cost for each process is about 15% of the installed cost or $3,900 and $4,900, respectively. This report also states that the process requires no operator attention. However, operating labor is estimated at 3 hr/day for routine checks on the process to see that it functions properly.

Periodically, the sludge must be removed and landfilled or incinerated. The cost of sludge removal is included in the maintenance cost. The cost of land for landfill or the cost of incineration process is excluded in this estimate.

Blecker and Nichols (1973) report that the expected life of these systems is between 25 and 60 years, and the life is taken to be 40 years for the purpose of depreciation of the installed costs. (See Appendix B.)

Filtration Process Costs - The wastewater is pumped from the sedimentation process (at the same rate as the inflow) into a sand filter to further remove suspended solids. The flow rate through a sand filter can vary depending upon the design, but a typical flow rate according to Envirogenics Systems Company (1973) is about 3.2 gal/sq ft/min. Thus, the required filter area for the 200 and 300 gpm flows is about 70 and 100 sq ft, respectively. A back-up filter is required for each process since the plant operates 24 hr/day.

The installed cost for the filtration process is obtained from the report by Blecker and Nichols (1973). The graph on page 66 of this report shows that the installed cost of a 70 sq ft filter is $50,000 and a 100 sq ft filter is $60,000. Since these costs are in 1972 dollars, the April 1975 costs (rounded) are:

200 gpm filtration process: $(2)(\$50,000)\left(\frac{180.6}{137.2}\right) = \$131,600$

300 gpm filtration process: $(2)(\$60,000)\left(\frac{180.6}{137.2}\right) = \$158,000$

Blecker and Nichols (1973) reported that the annual maintenance cost for each process is about 5% of the installed cost or $6,600 and $7,900, respectively. This report states that the filtration process requires no operator attention. However, operating labor is estimated at 3 hr/day for routine checks on the process to see that it functions properly.

Periodically, the filters are backwashed into a sump to remove the filtered solids. Removal of the sludge from the pit is included in the maintenance costs given above. The cost of land for landfill or the cost of incineration of the sludge is excluded in this estimate.

Blecker and Nichols (1973) reported that the expected life of the filtration process is between 10 and 20 years and is taken to be 15 years for the purpose of depreciation of the installed costs (see Appendix B).

Resin Adsorption System Costs - Velsicol Chemical Corporation designed a system and estimated the costs for an Amberlite XAD-4 resin process to treat 100 gpm of wastewater. A system is described and the costs are estimated in their R&D grant application submitted to EPA to conduct a project entitled, "Chlorinated Hydrocarbon Pesticide Removal from Wastewater," In another document written by Marks (September 1974), the installed capital equipment costs (1973 dollars) were estimated by Velsicol to be $60,000 (excluding the filtration process) for purchased parts and $27,000 for installation of the process, or a total of $87,600. These costs were itemized by Velsicol as follows:

Purchased Parts

2 Resin columns with headers	$16,000	
2 Solvent tanks	22,000	
3 Transfer pumps	6,000	
Instrumentation	4,000	
Valves and piping	4,800	
Contingency on purchased parts	7,200	
	$60,000	$60,000

Subcontracts

Mechanical and electrical construction	$22,000	
Slab and related civil works	5,600	
	$27,600	27,600
Total cost		$87,600

Chemical Engineering (1975a) shows that the 1973 CE plant cost index was 144.1 so that the April 1975 estimated cost of the XAD-4 resin process is:

$$(\$87,600)\left(\frac{180.6}{144.1}\right) = \$110,000$$

This cost is for a 100 gpm flow rate and must be scaled up to 200 and 300 gpm, respectively. Since this process involves tanks, pumps, piping, and resin columns, the best available method to scale up this plant is the logarithmic relationship known as the "six-tenths factor" (see Appendix B). Using this method, the installed cost for the XAD-4 resin process is:

$$\text{200 gpm process: } (\$110,000)\left(\frac{200}{100}\right)^{0.6} = \$167,000$$

$$\text{300 gpm process: } (\$110,000)\left(\frac{300}{100}\right)^{0.6} = \$212,700$$

These costs do not include the cost of neutralizing the treated wastewater. Since the current practice at Hercules is to neutralize the toxaphene wastewater with limestone prior to treatment, the only cost added by the XAD-4 resin system would be the cost of the limestone since the neutralization process facility already exists.

The cost of the limestone is negligible in this treatment system compared to the cost of the resin and isopropyl alcohol (discussed subsequently) since the amount of limestone required to neutralize the wastewater is less than the amount of sodium carbonate required in the reductive degradation system (Cywin, 1973), which amounts to 44,100 lb/year for a 100 gpm plant. The cost of limestone is only about one-tenth the cost of sodium carbonate, or about $10/ton (Cywin, 1973). On an annual basis, this amounts to a cost of $220 to neutralize the wastewater of a 100 gpm plant. For the 200 gpm and 300 gpm plants the annual costs would be $440 and $660, respectively, which are negligible in this case.

The material costs are essentially the Amberlite XAD-4 resin and the isopropyl alcohol used to regenerate the contaminated resin columns. Velsicol (Vitalis, 1975) estimates that the cost of the resin to charge the resin columns for the 100 gpm system is $63,000 (current prices) and that the resin has an operating lifetime of 5 years. Rohm and Haas Company (Kennedy, 1973) estimates that the cost of the regeneration isopropyl alcohol makeup is $30,000 per year (1972 prices) for a 100 gpm process. The average 1972 price of isopropyl alcohol was about $0.45/gal (Oil, Paint and Drug, 1972) and the current price is $0.70/dal (Chemical Marketing Reporter, 1975), so that the isopropyl alcohol cost in April 1975 prices is (0.70/0.45) ($30,000) or $46,700/year for a 100 gpm plant.

Using a linear relationship to scale up the resin and isopropyl alcohol required for the two process flow rates gives:

Resin:

200 gpm process: $\$63{,}000 \left(\frac{200}{100}\right) = \$126{,}000$

300 gpm process: $\$63{,}000 \left(\frac{300}{100}\right) = \$189{,}000$

Isopropyl alcohol:

200 gpm process: $(\$46{,}700/\text{year}) \left(\frac{200}{100}\right) = \$93{,}400/\text{year}$

300 gpm process: $(\$46{,}700/\text{year} \left(\frac{300}{100}\right) = \$140{,}100/\text{year}$

Blecker and Nichols (1973) reported that the annual maintenance cost for each process is about 5% of the installed equipment cost, or $8,400 and $10,600, respectively.

The operating labor time is estimated at 9 man-hours/day on a 24 hr/day operating basis for the 100 gpm system based upon the estimates given for ion exchangers (Blecker and Nichols, 1973). This gives a requirement of 3,150 man-hours annually (based on 350 operating days/year). To scale this labor time up to the 200 and 300 gpm process flow rates, the "one-fourth factor" is used (Popper, 1970). This method (see Appendix B) gives the estimated operating labor time for each process as follows:

200 gpm process operating labor: $(3{,}150 \text{ hr}) \left(\frac{200}{100}\right)^{0.25} = 3{,}750 \text{ hr}$

300 gpm process operating labor: $(3{,}150 \text{ hr}) \left(\frac{300}{100}\right)^{0.25} = 4{,}150 \text{ hr}$

Rohm and Haas (Kennedy, 1973) estimates that the expected life of the XAD-4 resin process equipment is 10 years and that the life of XAD-4 resin

charge is 5 years for the purpose of depreciation of the installed costs of the capital equipment and resin.

Reductive Degradation System Costs - Envirogenics Systems Company (Sweeny et al., December 1973) designed a pilot plant demonstration system and estimated the cost of a reductive degradation process to remove the endrin from wastewater flowing at 100 gpm. The system is fully described in the Envirogenics Report (Sweeny, December 1973) and the associated costs (1973 dollars) are given in detail.

In this document the installed capital equipment costs were estimated by Environgenics Systems Company (Sweeny, December 1973) to be $58,900. These costs were itemized as follows:

Purchased Parts

2 Reagent mix tanks, 200 gal. with mixers, low-level alarm and proportional feed pump	$3,000
1 Transfer pump with low-level alarm	1,000
1 pH adjustment tank, approximately 2,000 gal.	2,000
1 Mixer and impeller, 2 h.p.	3,000
1 Low and high level alarm for above	500
1 5 h.p. feed pump	700
1 pH sensing and control unit	2,000
5 Rotameters	900
Valves and piping	1,810
5 Reactor columns with distributors	10,000

Reagents	190
Total	25,100
Contingency on purchased parts	5,000
	30,100
Subcontracts	
Mechanical and electrical construction	20,000
Slab and related civil works	4,000
Total	24,000
Contingency on subcontracts	4,800
	28,800
Total	$58,900

The 1973 Chemical Engineering Plant Cost Index was 144.1 (Chemical Engineering, 1975a) so that the April 1975 cost of the reductive degradation process is:

$$(\$58,900)\left(\frac{180.6}{144.1}\right) = \$73,800$$

This cost is for a 100 gpm process and must be scaled up to 200 and 300 gpm, respectively. Since the process involves tanks, pumps, reactor columns, and miscellaneous equipment, the best available method for scale-up is the logarithmic relationship known as the "six-tenths factor," previously described (see Appendix B). Using this method, the installed cost for the reductive degradation process is:

200 gpm process: $\$73,800 \left(\frac{200}{100}\right)^{0.6} = \$111,900$

300 gpm process: $\$73,800 \left(\frac{300}{100}\right)^{0.6} = \$142,700$

The material costs for the system are the replacement of the iron reductant, the copper catalyst, and the sodium carbonate consumed in the process operation. Envirogenics Systems Company (Sweeny, December 1973) determined that the losses of iron reductant for processing existing endrin wastewater were 5.0 mg/liter of effluent, and losses of copper catalyst were 0.1 mg/liter of effluent. The amount of sodium carbonate required to adjust the pH of the wastewater to 7.0 was determined to be 126 lb/day for the 100 gpm plant. Sodium carbonate was used by Envirogenics and is used in this estimate, though its cost is higher than, say, lime. Since it is not known whether or not lime can be used as a neutralizing agent in this process, the savings realized from using the cheaper lime cannot be determined. The difference in price of the two neutralizing agents would not greatly affect the overall process cost.

The annual material usage for the 100 gpm process, then, is as follows:

Iron reductant: $\left(\frac{5.0 \text{ mg Fe}}{\text{liter}}\right)\left(\frac{100 \text{ gal.}}{\text{min}}\right)\left(\frac{3.85 \text{ liter}}{\text{gal.}}\right)\left(\frac{1,440 \text{ min}}{\text{day}}\right)\left(\frac{2.2 \times 10^{-6} \text{ lb}}{\text{mg}}\right)\left(\frac{350 \text{ day}}{\text{year}}\right)$

$= \underline{2,130 \text{ lb/year}}$

Copper catalyst: $\left(\frac{0.1 \text{ mg Cu}}{\text{liter}}\right)\left(\frac{100 \text{ gal.}}{\text{min}}\right)\left(\frac{3.85 \text{ liter}}{\text{gal.}}\right)\left(\frac{1,440 \text{ min}}{\text{day}}\right)\left(\frac{2.2 \times 10^{-6} \text{ lb}}{\text{mg}}\right)\left(\frac{350 \text{ day}}{\text{year}}\right)$

$= \underline{45 \text{ lb/year}}$

Sodium carbonate: $\left(\frac{126\ \text{lb}}{\text{day}}\right)\left(\frac{350\ \text{days}}{\text{year}}\right) = \underline{44{,}100\ \text{lb/year}}$

The costs of replacing the iron reductant and copper catalyst are negligible since iron powder costs \$0.20/lb and copper sulfate costs \$0.70/lb (Chemical Marketing Reporter, 1975), and the quantities are quite small. The sodium carbonate cost, however, is substantial since its current price is about \$100/ton (Chemical Marketing Reporter, 1975) and a large quantity is required. The sodium carbonate needed for the 200 gpm and 300 gpm processes is proportional to the flow rate so that the annual cost of sodium carbonate for the two plants is:

200 gpm plant: $\left(\frac{44{,}100\ \text{lb}}{\text{year}}\right)\left(\frac{200}{100}\right)\left(\frac{\$0.05}{\text{lb}}\right) = \$4{,}400/\text{year}$

300 gpm plant: $\left(\frac{44{,}100\ \text{lb}}{\text{year}}\right)\left(\frac{300}{100}\right)\left(\frac{\$0.05}{\text{lb}}\right) = \$6{,}600/\text{year}$

Blecker and Nichols (1973) reported that the annual maintenance costs are 5% of the installed capital equipment costs, or \$5,600 and \$7,100 for the 200 gpm and 300 gpm processes, respectively.

The operating labor time is estimated at 9 man-hours/day on a 24 hr/day operating basis. This gives a requirement of 3,150 man-hours annually (based on 350 operating days/year). Scaling this labor time up to the 200 and 300 gpm processes is accomplished with the "one-fourth"factor," previously mentioned, and the annual operating labor time for each process becomes:

200 gpm process operating labor: $(3{,}150 \text{ hr}) \left(\frac{200}{100}\right)^{0.25} = 3{,}750 \text{ hr}$

300 gpm process operating labor: $(3{,}150 \text{ hr}) \left(\frac{300}{100}\right)^{0.25} = 4{,}150 \text{ hr}$

The expected life of the reductive degradation process equipment is taken to be 10 years for the purpose of depreciation of the installed equipment costs (see Appendix B).

Costs for the Resin Adsorption System and Reductive Degradation System in Series - The cost of a system which puts the XAD-4 resin system and reductive degradation system in series is the same as the sum of the costs for each separate system with only one exception: Only one sedimentation and one filtration process is necessary for the two systems in series, that is, each system does not have a separate sedimentation and filtration process. Therefore, the cost of the two systems in series is the sum of the cost of the two separate systems less the cost of one sedimentation process and one filtration process.

The fact that the toxaphene content of the wastewater treated by the reductive degradation system is lower, since the wastewater has already been treated by the XAD-4 resin system, does not reduce the cost of the reductive degradation system in series to any extent for two reasons: (a) The amount of wastewater treated is the same for the reductive degradation system whether alone or in series with the XAD-4 resin system, and the reductive degradation system must be of approximately the same size in both cases; and (b) the loss of iron reductant and copper catalyst will be lower for

the reductive degradation system in series but the cost of operating the system in series is unaffected since the cost of replacing these materials is negligible.

Total Capital Investment Costs for the Resin Adsorption System and the Reductive Degradation System - The cost of purchasing and installing the capital equipment for each system has been presented in the previous discussions. In addition to the previous cost estimates a contingency of 30% is added to these costs to allow for unanticipated expenses. Table 7 summarizes and totals the capital investment for the three systems.

Annual Operating Costs for the Resin Adsorption System and the Reductive Degradation System

The total annual costs to operate each system at both the 200 and 300 gpm flow rates are estimated below. Most of these costs are a percentage of either the installed capital equipment cost or the labor costs previously described. The following list shows all of the cost items considered in this estimate.

Direct costs

- Materials
- Labor
- Supervision
- Payroll charges
- Maintenance
- Operating supplies
- Utilities
- Laboratory services

Indirect costs

- Depreciation
- Property taxes
- Insurance
- Capital cost
- Plant overhead

Table 7. INSTALLED CAPITAL EQUIPMENT COST FOR THE XAD-4 RESIN SYSTEM, THE REDUCTIVE DEGRADATION SYSTEM, AND THE XAD-4 RESIN SYSTEM AND REDUCTIVE DEGRADATION SYSTEM IN SERIES

	XAD-4 resin system		Reductive degradation system		Two systems in series	
	200 gpm	300 gpm	200 gpm	300 gpm	200 gpm	300 gpm
Sedimentation	26,300	32,900	26,300	32,900	26,300	32,900
Filtration	131,600	158,000	131,600	158,000	131,600	158,000
XAD-4 resin process						
Equipment	167,000	212,700	-	-	167,000	212,700
Resin	126,000	189,000	-	-	126,000	189,000
Reductive degradation system	-	-	111,900	142,700	111,900	142,700
Subtotal	450,900	592,600	269,800	333,600	562,800	735,300
Contingency, 30%	135,300	177,800	80,900	100,100	168,800	220,600
Total (1975 $)	586,200	770,400	350,700	433,700	731,600	955,900

Materials - The only material cost of any consequence is the sodium carbonate used to neutralize the wastewater and the isopropyl alcohol used to regenerate the resin (the Amberlite XAD-4 has a 5 year useful life and is depreciated with the capital equipment). These costs have been previously given.

Labor - Labor costs are wages paid to operating labor. The total annual labor required for the three systems (based on 350 operating days/year) is:

	Annual man-hours					
	XAD-4 resin system		Reductive degradation system		Two systems in series	
Process	200 gpm	300 gpm	200 gpm	300 gpm	200 gpm	300 gpm
Sedimentation	1,050	1,050	1,050	1,050	1,050	1,050
Filtration	1,050	1,050	1,050	1,050	1,050	1,050
XAD-4 resin process	3,750	4,150	-	-	3,750	4,150
Reductive degradation process	-	-	3,750	4,150	3,750	4,150
Total	5,850	6,250	5,850	6,250	9,600	10,400

The hourly earnings of production or nonsupervisory workers in the chemical and allied products industry was $5.18/hr in March 1975 (Monthly Labor Review, 1975). For April 1975, the estimated wage rate is $5.20/hr. This gives an annual operating labor cost for each of the systems as follows:

System	Flow rate (gpm)	Annual man-hours	Hourly wage	Annual operating labor cost
XAD-4 resin	200	5,850	$5.20	$30,400
	300	6,250	5.20	32,500
Reductive degradation	200	5,850	5.20	30,400
	300	6,250	5.20	32,500
Two systems in series	200	9,600	5.20	49,900
	300	10,400	5.20	54,100

Supervision - Supervision of labor is normally estimated as a percentage of operating labor, a typical value being 20% (Jelen, 1970). Using this typical value of 20% of operating labor costs for labor supervision costs gives the following estimates:

	XAD-4 resin system		Reductive degradation system		Two systems in series	
	200 gpm	300 gpm	200 gpm	300 gpm	200 gpm	300 gpm
Annual labor supervision cost	$6,100	$6,500	$6,100	$6,500	$10,000	$10,800

Payroll charges - These costs are the result of the many fringe benefits employees receive in addition to their salaries. Recent emphasis on these benefits in labor contracts make this cost substantial and it is steadily increasing with time. According to Perry and Chilton (1973), the sum of fringe benefits may add between 15 and 40% to the wage rate of employees, and this varies widely from company to company. In this estimate, payroll charges (fringe benefits) are taken to be 30% of the wages paid to both labor and supervision. These payroll charges are thus estimated to be:

System	Flow rate (gpm)	Total operating labor and supervision cost	Payroll Charge
XAD-4 resin	200	$36,500	$11,000
	300	39,000	11,700
Reductive degradation	200	36,500	11,000
	300	39,000	11,700
Two systems in series	200	59,900	18,000
	300	64,900	19,500

Maintenance - Maintenance costs have been determined previously for each process. They are summarized here to give the total annual maintenance costs for each system.

	Annual maintenance cost ($)					
	XAD-4 resin system		Reductive degradation system		Two systems in series	
Process	200 gpm	300 gpm	200 gpm	300 gpm	200 gpm	300 gpm
Sedimentation	$3,900	$4,900	$3,900	$4,900	$3,900	$4,900
Filtration	6,600	7,900	6,600	7,900	6,600	7,900
XAD-4 resin process	8,400	10,600	-	-	8,400	10,600
Reductive degradation process	-	-	5,600	7,100	5,600	7,100
Total	$18,900	$23,400	$16,100	$19,900	$24,500	$30,500

Operating supplies - Operating supplies are items such as lubricating oil, instrument charts, etc., that are neither raw nor repair materials. The cost of these items is typically 6% of labor costs (Jelen, 1970). This amounts to an annual cost for operating supplies of:

	XAD-4 resin system		Reductive degradation system		Two systems in series	
	200 gpm	300 gpm	200 gpm	300 gpm	200 gpm	300 gpm
Annual operating supplies cost	$1,800	$2,000	$1,800	$2,000	$3,000	$3,200

Utilities - The utilities required for the processes are primarily electrical power. Little water is required if we assume that processed wastewater is recycled to the filter backwash and sodium carbonate mixing tanks. The estimated annual electrical cost for the 100 gpm reductive degradation system is $1,350; for the XAD-4 resin system is $650 (Marks, September 1974); and for pumping 100 gpm of wastewater in the sedimentation and filtration process is $100.

These costs are scaled up by direct proportion to give an annual electrical cost to each system as follows:

	Annual electrical costs ($)					
	XAD-4 resin system		Reductive degradation system		Two systems in series	
Process	200 gpm	300 gpm	200 gpm	300 gpm	200 gpm	300 gpm
Sedimentation and filtration	200	300	200	300	200	300
XAD-4 resin process	1,300	2,000	-	-	1,300	2,000
Reductive degradation process	-	-	2,700	4,100	2,700	4,100
Total	1,500	2,300	2,900	4,400	4,200	6,400

Laboratory services - Laboratory services furnished to support the treatment processes and monitoring operations are estimated at 20% of labor cost (Jelen, 1970). The annual laboratory services cost for the systems, therefore, are:

	XAD-4 resin system		Reductive degradation system		Two systems in series	
	200 gpm	300 gpm	200 gpm	300 gpm	200 gpm	300 gpm
Annual laboratory service cost	$6,100	$6,500	$6,100	$6,500	$10,000	$10,800

Depreciation - Depreciation is a periodic charge that distributes the installed capital investment cost over its expected service life. The cost estimate uses straight line depreciation and assumes all capital assets have a zero salvage value (see Appendix B). The capital investment costs and expected lives of all depreciable assets have been previously given and are used below to determine the annual depreciation cost for the three systems (rounded to nearest $100).

		Annual depreciation cost ($)					
		XAD-4 resin system		Reductive degradation system		Two systems in series	
Capital asset	Life (years)	200 gpm	300 gpm	200 gpm	300 gpm	200 gpm	300 gpm
Sedimentation process	40	900	1,100	900	1,100	900	1,100
Filtration process	15	11,400	13,700	11,400	13,700	11,400	13,700
XAD-4 resin process	10	21,700	27,700	-	-	21,700	27,700
XAD-4 resin charge	5	32,800	49,100	-	-	32,800	49,100
Reductive degradation process	10	-	-	14,600	18,600	14,600	18,600
Total		66,800	91,600	26,900	33,400	81,400	110,200

Property taxes, insurance, and capital costs - Property taxes, insurance and capital costs are estimated as a percentage of the installed capital equipment cost. These costs are calculated and reported in this report separately to show the cost breakdown of these three items.

Jelen (1970) reports that property taxes are taken to be 2% of investment cost, and that insurance is generally about 1% of investment cost. Capital cost (or interest) is a charge to finance the investment expenditures. This

interest may be a real cost when funds are borrowed to finance the investment, or an assumed cost when internal funds are used (since internal funds would earn interest if loaned out rather than purchase capital assets). The annual rate of interest (see Appendix B) has varied widely in the recent past and is taken to be 10% for 10 years due to current market interest rates and current cost literature (Chemical Engineering, 1975b). As shown in Appendix B, this is equivalent to an annual interest rate of 6.3% of capital investment.

Using the above percentage gives the following indirect costs for the three systems:

	Annual cost ($)					
	XAD-4 resin process		Reductive degradation system		Two systems in series	
Cost item	200 gpm	300 gpm	200 gpm	300 gpm	200 gpm	300 gpm
Property taxes (2%)	11,700	15,400	7,000	8,700	14,600	19,100
Insurance (1%)	5,900	7,700	3,500	4,300	7,300	9,600
Capital cost (6.3%)	36,900	48,500	22,100	27,300	46,100	60,200

Plant overhead - Plant overhead is a charge to the costs of the manufacturing facility which are not chargeable to any particular operation and are normally charged on an allotted basis. Overhead includes such cost items as plant supervision, plant guards, janitors, cafeterias, administrative offices, accounting, purchasing, etc. Overhead costs will vary from company to company and are usually calculated as a percentage of direct labor cost or a percentage of installed capital investment for the entire

facility, and allocated to each operation based on its labor or investment cost.

Jelen (1970) reports that plant overhead can range from 40 to 60% of direct labor costs or 15 to 30% of direct costs. In this report, the plant overhead is estimated to be 20% of the direct costs.

Total Cost Estimates for the Resin Adsorption System and the Reductive Degradation System

The total costs of the resin adsorption system, the reductive degradation system and the two systems in series are given in Table 8. The table shows that the total installed capital equipment costs for the three systems are: (a) XAD-4 resin system, $586,200 (200 gpm) and $770,400 (300 gpm); (b) reductive degradation system, $350,700 (200 gpm) and $433,700 (300 gpm); and (c) the two systems in series, $731,600 (200 gpm) and $955,900 (300 gpm). The estimated total annual operating costs are: (a) $324,300 and $433,200; (b) $154,100 and $181,800; and (c) $410,300 and $537,500, respectively. The estimated cost (per 1,000 gal. of effluent) of treating the toxaphene wastewater effluent is (a) $3.21 and $2.87; (b) $1.53 and $1.20; and (c) $4.07 and $3.55, respectively. The estimated unit operating cost to treat toxaphene wastewater per pound of toxaphene product (based on 50 million pounds of annual production) are: (a) $0.0065 and $0.0087; (b) $0.0031 and $0.0036; and (c) $0.0082 and $0.0108, respectively. (The current sale price of toxaphene is reported to be 38 to 40c/lb (Meiners and Mumma, 1975b)).

Table 8. TOTAL INVESTMENT COST AND ANNUAL OPERATING COST FOR THREE TOXAPHENE WASTEWATER TREATMENT SYSTEMS TREATING EITHER 200 OR 300 GAL/MIN WASTEWATER EFFLUENT

Cost item	XAD-4 resin system		Reductive degradation system		Two systems in series	
	200 gpm	300 gpm	200 gpm	300 gpm	200 gpm	300 gpm
Total installed capital equipment cost (1975 $)	586,200	770,400	350,700	433,700	731,600	955,900
Annual operating costs (1975 $)						
Direct costs						
Materials	93,400	140,100	4,400	6,600	97,800	146,700
Labor	30,400	32,500	30,400	32,500	49,900	54,100
Supervision	6,100	6,500	6,100	6,500	10,000	10,800
Payroll charges	11,000	11,700	11,000	11,700	18,000	19,500
Maintenance	18,900	23,400	16,100	19,900	24,500	30,500
Operating supplies	1,800	2,000	1,800	2,000	3,000	3,200
Utilities	1,500	2,300	2,900	4,400	4,200	6,400
Laboratory	6,100	6,500	6,100	6,500	10,000	10,800
Subtotal	169,200	225,000	78,800	90,100	217,400	282,000

Table 8 (Concluded)

Cost item	XAD-4 resin system		Reductive degradation system		Two systems in series	
	200 gpm	300 gpm	200 gpm	300 gpm	200 gpm	300 gpm
Indirect costs						
Depreciation	66,800	91,600	26,900	33,400	81,400	110,200
Property taxes	11,700	15,400	7,000	8,700	14,600	19,100
Insurance	5,900	7,700	3,500	4,300	7,300	9,600
Capital cost	36,900	48,500	22,100	27,300	46,100	60,200
Plant overhead	33,800	45,000	15,800	18,000	43,500	56,400
Subtotal	155,100	208,200	75,300	91,700	192,900	255,500
Total annual operating costs (1975 $)	324,300	433,200	154,100	181,800	410,300	537,500
Unit operating costs						
Cost ($)/1,000 gal. effluent	3.21	2.87	1.53	1.20	4.07	3.55
Cost, $/lb of toxaphene (50 million pounds produced in 1975)	0.0065	0.0087	0.0031	0.0036	0.0082	0.0108

Carbon Adsorption Process Costs

As indicated in Figure 12, the toxaphene process wastewater will require (a) sedimentation, (b) filtration, and (c) neutralization prior to adsorption on carbon. The costs of sedimentation and filtration have been discussed earlier in this report, and the costs of the neutralization were discussed in the portion of this report dealing with the costs of the reductive degradation process.

The capital equipment costs of the carbon adsorption unit in the system are estimated below at two contact times. Following this are the cost summaries for the entire system which includes sedimentation, filtration, neutralization and carbon adsorption.

A conceptual flow diagram for a carbon adsorption process is shown in Figure 12. The portions of this process which deal with removal of suspended solids and pH adjustment in the wastewater are taken to be identical to the process steps of sedimentation, filtration and neutralization, which are used in the reductive degradation system. Hager (1974) indicates that suspended solids in amounts exceeding about 50 mg/liter should be removed prior to treatment of effluent in carbon adsorption beds and that pH adjustment can be employed to enhance adsorption efficiency.

Following removal of suspended solids, the wastewater is conducted through a two-stage carbon adsorption system which consists essentially of (a) two on-stream carbon adsorption units operating in series and one standby unit packed with granular activated carbon, and (b) the required auxiliary equipment (pumps, piping, process instrumentation, etc.).

When the concentration of toxaphene in the effluent from the first unit is equivalent to the feed concentration the carbon in the unit is exhausted and the unit is taken off stream (Hutchins, 1975a). The second unit then becomes the lead unit and the standby column is put on stream as the second column in the series. The exhausted unit is discharged, refilled with fresh carbon, and used as standby. Because of the small requirement for activated carbon, regeneration of the carbon is not economically justified (Hutchins, 1975b). The exhausted carbon is disposed of by incineration; the costs for incineration are not included in this study.

The cost of a carbon adsorption process to treat 300 gpm of toxaphene contaminated wastewater is estimated from cost information obtained from two sources. The first source is Mr. Roy H. Hutchins, Development Associate, Product Development Department, ICI United States, Inc., Wilmington, Delaware (Hutchins, 1975a). The second source is a process design manual for carbon adsorption (Cornell, 1973).

The treatability of a particular wastewater by activated carbon and the relative capacity of carbon for treatment can be estimated from adsorption isotherm data, obtained by batch testing. However, carbon performance and design criteria are best determined by pilot tests under dynamic flow conditions. The required contact time for a given carbon adsorber column (i.e., the residence time required for the wastewater in a carbon column) is an important design consideration for carbon adsorption systems. The contact time data can only be accurately determined by pilot tests which

simulate full-scale operating conditions. Unfortunately, contact time data of this type are not available. Therefore, two different assumed values of contact time were used in this study as a means for estimating a range of investment and operating costs. The two contact times considered were:

1. Thirty minute (30 min) contact time (15 min retention in each of two carbon columns in series). This retention time was shown to be effective for endrin by data reported by Robeck (1965) (Table 13, p. 198).

2. Sixty minute (60 min) contact time (30 min retention in each of two carbon columns in series).

Capital Investment Costs for Carbon Adsorption System with 30 Min Contact Time

As recommended by Hutchins (1975a) the adsorption isotherm in Figure 8 by Hager (April 1974) was extrapolated to determine the toxaphene removal per unit of carbon corresponding to a toxaphene concentration of 500 ppb (i.e., the estimated concentration in the wastewater to be treated by carbon adsorption). The value obtained by extrapolation is 7% weight pickup. This isotherm applies for carbon contact with toxaphene in distilled water. Robeck (1965, Figure 6, p. 192) shows a relationship between the adsorption capacities; the adsorption capacity is greater in distilled water than in river water. River water most closely approximates the operating conditions which would be encountered. Making an adjustment for river water results in a loading value of about 3.9% (0.039 lb pesticide adsorbed per pound of carbon used).

The total quantity of toxaphene to be removed per day (reduction from 500 to < 5 ppb) by the conceptual adsorption system is estimated by considering that final effluent may contain 2 ppm toxaphene.

300 gpm x 3.785 liter/gal x 500 µg/liter = 567,750 µg/min, toxaphene entering

300 gpm x 3.785 liter/gal x 2 µg/liter = 2,270 µg/min, toxaphene leaving

Difference (rounded) = ~ 565,500 µg/min, toxaphene retained on carbon

The estimated carbon requirement at 3.9% pickup is:

$$\frac{0.565 \text{ g/min} \times 60 \times 24}{453.6 \times 0.039} = 46 \text{ lb carbon required per day}$$

Hutchins (1975a) has stated that the efficient use of carbon in the adsorption system can be maximized by a counter-current type of operation as depicted in Figure 12. In this conceptual process, two adsorber columns are operated in series continuously, while a third adsorber unit is always held on standby. All three columns would have the same physical size and initial fresh carbon charge. When break-through occurs in the first absorber (i.e., the total charge becomes fully spent) the unit is taken out of service. The second column then becomes the lead column (No. 1), and the standby adsorber is then placed in service as the second adsorber. The original No. 1 adsorber column is then discharged, the spent carbon disposed of as solid waste to be incinerated and the drained wastewater is reprocessed through the system; the column is then recharged with fresh carbon and held on standby for a subsequent repetition of the operation

described above. In this arrangement there is no regeneration of spent carbon. Hutchins (1975a) has estimated that one carbon unit (~ 12,000 lb C) would become spent about every 5 months.

On the basis of data provided by Robeck (1965) and Cornell (1973) and at the recommendation of Hutchins (1975a), it was considered that the two on-stream adsorbers would have a total wastewater to carbon contact time of 30 min (i.e., 15 min contact in each of two adsorbers) and that the flow rate through the carbon bed would be 4 gpm/ft^2 of adsorber bed cross-sectional area.

At 300 gpm, a 15 min contact time corresponds to a holding volume per vessel of 300 x 15 or 4,500 gal. or 602 ft^3. Cornell (1973) recommends 50% additional adsorber volume to provide for backwash operations. Thus, the total volume of each vessel would be 1.5 x 4,500 or 6,750 gal. or 903 ft^3. On this basis, the size of each contactor would be approximately 10 ft I.D. ($\frac{300}{4}$ = 75 sq ft cross-sectional area) by about 11 ft high. Hutchins (1975a) has recommended an initial charge of 12,000 lb carbon* per vessel. Considering downflow operation of the contactors, the effective volume (carbon volume) in each adsorber (contactor) would be

$$\frac{12{,}000 \text{ lb}}{23 \text{ lb/ft}^3} = 522 \text{ ft}^3 \text{ (approximately a 7-ft bed depth of carbon)}$$

Cost for Carbon Contactor Units - Cost data reported by Cornell (1973) (Figure 5-1, p. 5-4) were used to estimate the installed cost for three

* Hydrodarco 4000 sold by ICI, United States, Inc.

equal-sized carbon adsorber columns (contactors). Cornell's Figure 5 relates the construction cost to effective contactor volume. Since the volume (522 ft^3) of the contactors considered in this study is off-scale on the low side in this figure, the 0.6 power factor relationship was used to estimate the contactor cost. A contactor with an effective volume of 1,000 ft^3 has a construction cost of \$80,000 (Figure 5-1, Cornell, 1973). By the 0.6 factor relationship (see Appendix B):

$$\$80,000 = \frac{1,000}{522}^{0.6} C \qquad C = \$54,200/\text{contactor}$$

Then, the cost for three contactors would be 3 x \$54,200 or \$162,600. Updating this cost for inflationary changes using Marshall and Swift cost indices for 1975 and 1973 gives:

$$\frac{443.8}{344.1} \times \$162,600 = \$209,700$$

Cost for Influent Pump Station - As shown in the Cornell (1973) cost data (Figure 5-5, p. 5-11), the cost for an influent pump station for a 300 gpm or 0.43×10^3 gpd is about \$10,000. Updating by Marshall and Swift cost indices for 1973 and 1975 gives:

$$\frac{443.8}{344.1} \times \$10,000 = \$12,900$$

Initial Carbon Charge and Carbon Replacement Costs - As recommended by Hutchins (1975a) each of three contactors would have an initial charge of 12,000 lb of granular activated carbon (Hydrodarco 4000, ICI, United States, Inc.) at a cost of \$0.38/lb. Then,

3 x 12,000 x $0.38 = $13,700

Estimated make-up carbon costs (at 2 refills per year) is 2 x 12,000 x $0.38 = $9,100/year.

Plant investment costs for the carbon adsorption equipment (30 min contact system) are:

	Estimated Installed costs (1975 $)
Influent pump station	$ 12,900
Carbon contactors (3)	209,700
Initial carbon charge	13,700
Subtotal	$236,300
Adjustment to account for engineering, legal, administrative land and interst expenses, 20% of subtotal (Cornell, 1973)	47,000
Total	$283,300

Capital Investment Costs for Carbon Adsorption Unit with 60 Min Contact Time

At 300 gpm, a 30 min contact time in each carbon adsorber corresponds to a holding volume per vessel of 300 x 30 = 9,000 gal. or 1,204 ft^3. Cornell (1973) recommends 50% additional adsorber volume to provide for backwash operation. Thus, the total volume of each vessel would be 1.5 x 9,000 or 13,500 gal. For a flow rate of 4 gpm/ft^2, the cross-sectional area of each contactor would be $\frac{300}{4}$ = 75 ft^2 and the effective volume would be 2 x 522 or 1,044 ft^2.

Cost data by Cornell (1973) (Figure 5-1, p. 5-4) show that the cost for a contactor with 1,044 ft^3 of effective volume is about $80,000. For three contactors, the cost is 3 x $80,000 or $240,000. Updating by Marshall and Swift cost indices for 1975 and 1973 gives:

$$\frac{443.8}{344.1} = \$240,000 = \$309,500$$

The initial carbon charge would be twice as large as for the 30 min total contact system or 2 x $13,700 = $27,400.

It is considered that the influent pump station cost would be the same as for the 30 min contact system or $12,900.

Summary of Capital Investment - Estimated plant investment costs for the carbon adsorption equipment (60 min contact time) are:

Item	Estimated Installed Costs (1975 $)
Influent pump station	$ 12,900
Carbon contactors (3)	309,500
Initial carbon charge	27,400
Subtotal	$349,800
Adjustment to account for engineering, legal, administrative, land and interest expenses; 20% of subtotal (Cornell, 1973)	70,000
Total	$419,800

Summary of Installed Capital Equipment Costs - Table 9 summarizes the capital investments for the two carbon contact times considered in this study.

Table 9. INSTALLED CAPITAL EQUIPMENT COST FOR THE 300 GPM CARBON ADSORPTION SYSTEM

Process	Capital investment cost (1975 $) Contact time, 30 min	Contact time, 60 min
Sedimentation	$ 33,000	$33,000
Filtration	158,000	158,000
Carbon adsorption	283,300	419,800
Subtotal	474,300	610,800
Contingency, 30% (see Appendix B)	142,300	183,200
Total	$616,600	$794,000

Annual Operating Costs for Carbon Adsorption System (Including Sedimentation, Filtration, and Neutralization)

The total annual costs to operate the system at the 300 gpm flow rate are estimated below. Most of these costs are a percentage of either the installed capital equipment cost or the labor costs previously described. The following list shows all of the cost items considered in this estimate.

Direct costs

Materials
Labor
Supervision
Payroll charges
Maintenance
Operating supplies
Utilities
Laboratory services

Indirect costs

Depreciation
Property taxes
Insurance
Capital cost
Plant overhead

Operating Labor and Maintenance for Carbon Adsorption Plant - Operating labor time is estimated from cost data reported by Cornell (1973) (Figure 5-7, p. 5-18). The flow (432,000 gpd) for the conceptual carbon adsorption system is off-scale on Figure 5-7. The one-fourth factor (see Appendix B) is used to scale down labor requirements from one plant size to a smaller plant size. From Figure 5-7 (Cornell, 1973), the operating labor requirement for a flow of 2 MGD is 750 annual man-hours. Scaling down this value by the one-fourth factor (see Appendix B) gives:

$$750 = \left(\frac{2}{0.432}\right)^{0.25} C$$

C = 510 man-hours for a flow of 0.432 M gpd (300 gpm)

Operating labor time for the 60 min contact system is taken to be the same as for the 30 min contact system or 510 man-hours per year.

The annual maintenance cost for the carbon adsorption operation is estimated as 5% of capital investment (see Appendix).

For 30 min contact system, 0.05 x $283,300 = $14,200.

For 60 min contact system, 0.05 x $419,800 = $21,000.

Materials - The material costs are the limestone ($660/year) used to neutralize the wastewater and the activated carbon makeup each year ($9,100/year).

Labor - Labor costs are wages paid to operating labor. These costs are taken to be the same for the 30 and 60 min contact systems. The total annual operating labor required for the plant is:

Process	Annual man-hours
Sedimentation	1,050
Filtration	1,050
Neutralization	1,050
Carbon adsorption	510
Total	3,660

The hourly earnings of production or nonsupervisory workers in the chemical and allied products industry was $5.18/hr in March 1975 (Monthly Labor Review, May 1975). For April 1975, the estimated wage rate is $5.20/hr. This gives an annual operating labor cost of $19,000.

Supervision - Supervision of labor is normally estimated as a percentage of operating labor, a typical value being 20% (Jelen, 1970). Using this typical value of 20% of operating labor costs for labor supervision costs gives a cost of $3,800/year. (Applies for both 30 min and 60 min contact systems).

Payroll Charges - This cost is the result of the many fringe benefits employees receive in addition to their salaries. Recent emphasis on these benefits in labor contracts make this cost substantial and it is steadily increasing with time. The sum of fringe benefits may add between 15 and 40% to the wage rate of employees (Perry and Chilton, 1973), and this varies widely from company to company. In this estimate, payroll charges (fringe benefits) are taken to be 30% of the wages paid to both labor and supervision. This cost amounts to $6,800. (Applies for both the 30 min and the 60 min contact systems.)

Maintenance - Maintenance costs have been determined previously for each part of the process. They are summarized here to give the total annual plant maintenance costs.

Process	Annual maintenance	
	30 min system	60 min system
Sedimentation	$ 5,000	$ 5,000
Filtration	7,900	7,900
Neutralization	2,900	2,900
Carbon adsorption	14,200	21,000
Total	$30,000	$36,800

Operating Supplies - Operating supplies are items such as lubricating oil, instrument charts, etc., that are neither raw or repair materials. The cost of these items is typically 6% of labor costs (Jelen, 1970) and amounts to an annual cost of $1,100. (Applies for both 30 min and 60 min contact systems.)

Utilities - The utilities required for the process are primarily electrical power. The estimated annual electrical cost for this system estimated from cost data reported by Cornell (1973) (Figure 5-9, p. 5-20). Figure 5-9 shows an annual power cost (at $0.02/KWH) of 4,600/year. Adjusting from 1973 to 1975 by Marshall and Swift cost indices for electrical power industries gives $\frac{437.7}{322.2} \times 4{,}600 = \$6{,}200$. (Applies for both the 30 min and 60 min contact systems.)

Laboratory - Laboratory services furnished to support the treatment process operation are estimated at 20% of labor cost (Jelen, 1970) or $3,800/year. (Applies for both the 30 min and 60 min contact systems.)

Depreciation - Depreciation is a periodic charge that distributes the installed capital investment cost over its expected service life. This cost estimate uses straight line depreciation and assumes all capital assets have a zero salvage value. The capital investment costs and expected lives of all depreciable assets have been previously given and are summarized and totaled below (rounded to nearest $100):

Process	Life (years)	Annual depreciation cost ($)	
		30 min system	60 min system
Sedimentation	40	800	800
Filtration	15	10,500	10,500
Carbon adsorption	10	28,300	42,000
Total		39,600	53,300

Property Taxes, Insurance, and Capital Costs - Property taxes, insurance and capital costs are estimated as a percentage of the installed capital

equipment cost. These costs are calculated and reported in this report separately to show the cost breakdown of these three items.

Property taxes are taken to be 2% of investment cost, and insurance is generally about 1% of investment cost (Jelen, 1970). Capital cost (or interest) is a charge to finance the investment expenditures. This interest may be a real cost when funds are borrowed to finance the investment, or an assumed cost when internal funds are used (since internal funds would earn interest if loaned out rather than used to purchase capital assets). The annual rate of interest has varied widely in the recent past and is taken to be 6.3% per annum (see Appendix B).

Using the above percentages gives the following indirect costs for this system:

Cost item	Annual cost ($)	
	30 min contact system	60 min contact system
Property taxes (2%)	12,300	15,900
Insurance (1%)	6,200	7,900
Capital cost (6.3%)	38,800	50,000

Plant Overhead - Plant overhead is a charge to the costs of the manufacturing facility which are not chargeable to any particular operation and are normally charged on an allotted basis. Overhead includes such cost items as plant supervision, plant guards, janitors, cafeterias, administrative offices, accounting, purchasing, etc. Overhead costs will vary from company to company and are usually calculated as a percentage of direct labor or a percentage of installed capital investment for the entire

facility, and allocated to each operation based on its labor or investment cost.

Plant overhead can range from 40 to 60% of direct labor costs or 15 to 30% of direct costs (Jelen, 1970). We estimate that plant overhead is 20% of direct costs in this report.

Total Cost for Carbon Adsorption System (Including Costs of Sedimentation, Filtration, and Neutralization)

The total cost of the carbon adsorption system is the sum of the total capital investment costs plus the annual operating cost. These costs have been estimated in the preceding three sections of this report.

The total estimated capital investment costs for the carbon adsorption system are presented in Table 10.

Table 10. ESTIMATED TOTAL INVESTMENT AND ANNUAL OPERATING COSTS FOR GRANULAR ACTIVATED CARBON ADSORPTION SYSTEMS (300 gpm Toxaphene Wastewater Flow Rate)

Carbon adsorption system total contact time, min	Costs $ (1975) 30	60
Cost item		
Total installed capital equipment cost (including costs for sedimentation and filtration equipment)	616,600	794,000
Annual operating costs:		
Direct costs		
Materials	9,800	9,800
Operating labor	19,000	19,000
Supervision	3,800	3,800
Payroll charges	6,800	6,800
Maintenance	30,000	36,800
Operating supplies	1,100	1,100
Utilities	6,200	6,200
Laboratory charges	3,800	3,800
Subtotal	80,500	87,300
Indirect costs		
Depreciation	39,600	53,300
Property taxes and insurance	18,500	23,800
Capital cost (interest)	38,800	50,000
Plant overhead	16,100	17,500
Subtotal	113,000	144,600
Total (rounded)	194,000	232,000
Unit operating costs		
Cost ($)/1,000 gal. effluent	$1.28	$1.53
Cost, $/lb of toxaphene product (50 million pounds product in 1975)	0.0039	0.0046

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APPENDIX A

ENGINEERING INFORMATION PERTINENT TO TOXAPHENE WASTE TREATMENT AT THE HERCULES, INC., PLANT AT BRUNSWICK, GEORGIA

The information contained in this Appendix was obtained from an engineering report supplied by Mr. C. L. Dunn, Manager, Ecological Research, Hercules, Inc., to Mr. Richard K. Ballentine, Toxic Substances Branch, EPA, on December 16, 1975. This information was not received in time to be incorporated into the toxaphene manufacture report.

A. Background

Systematic sampling and determination of toxaphene content of Brunswick Plant waste effluent was undertaken in 1970. Monitoring prior to that time was done on an irregular schedule, but had identified toxaphene as an undesirable pollutant. Various methods for toxaphene pollution abatement were studied, including adsorption, thermal and chemical decomposition. Deep well injection was studied intensively and Earth Science, Inc., was contracted to develop a preliminary proposal which was completed January 20, 1969. Additional proposals were obtained from International Pollution Control, Inc., and Dow Chemical Company. Although the reports were generally favorable, both the Georgia Water Quality Commission and Hercules, Inc., had reservations about the desirability of this concept. By mutual agreement, this concept was dropped from consideration in the spring of 1970. Reconsideration of alternative treatment methods resulted in the design and installation of the present system. The Georgia Water Quality Commission issued a construction permit in early 1971, and the system was completed in stages during 1972. A schematic drawing of the toxaphene process and the related pollution abatement system can be found in Figure A-1.

B. Description of System

1. Containment

It was recognized from the beginning that the process area, packaging area, storage areas and all areas that might be contaminated with toxaphene would have to be enclosed by dikes, curbs or other suitable barriers. All process water and rainfall runoff is presently collected and treated. The area contained is indicated in Figure A-2, an aerial photo of the Toxaphene Area.

2. Sumps and Settling Tanks

All process water, spillage, floor drainings, etc., from the process area is treated in a settling tank to separate, recover and recycle any free toxaphene or toxaphene solution. A system of sumps is used for the same purpose in the solution makeup, packaging and shipping areas. Rainwater runoff is also passed through a number of sumps and toxaphene or toxaphene solution is also collected in these sumps and recycled.

3. Neutralization

All wastewater from the process area is neutralized. Since the bulk of this stream consists of dilute, waste by-product hydrochloric acid,

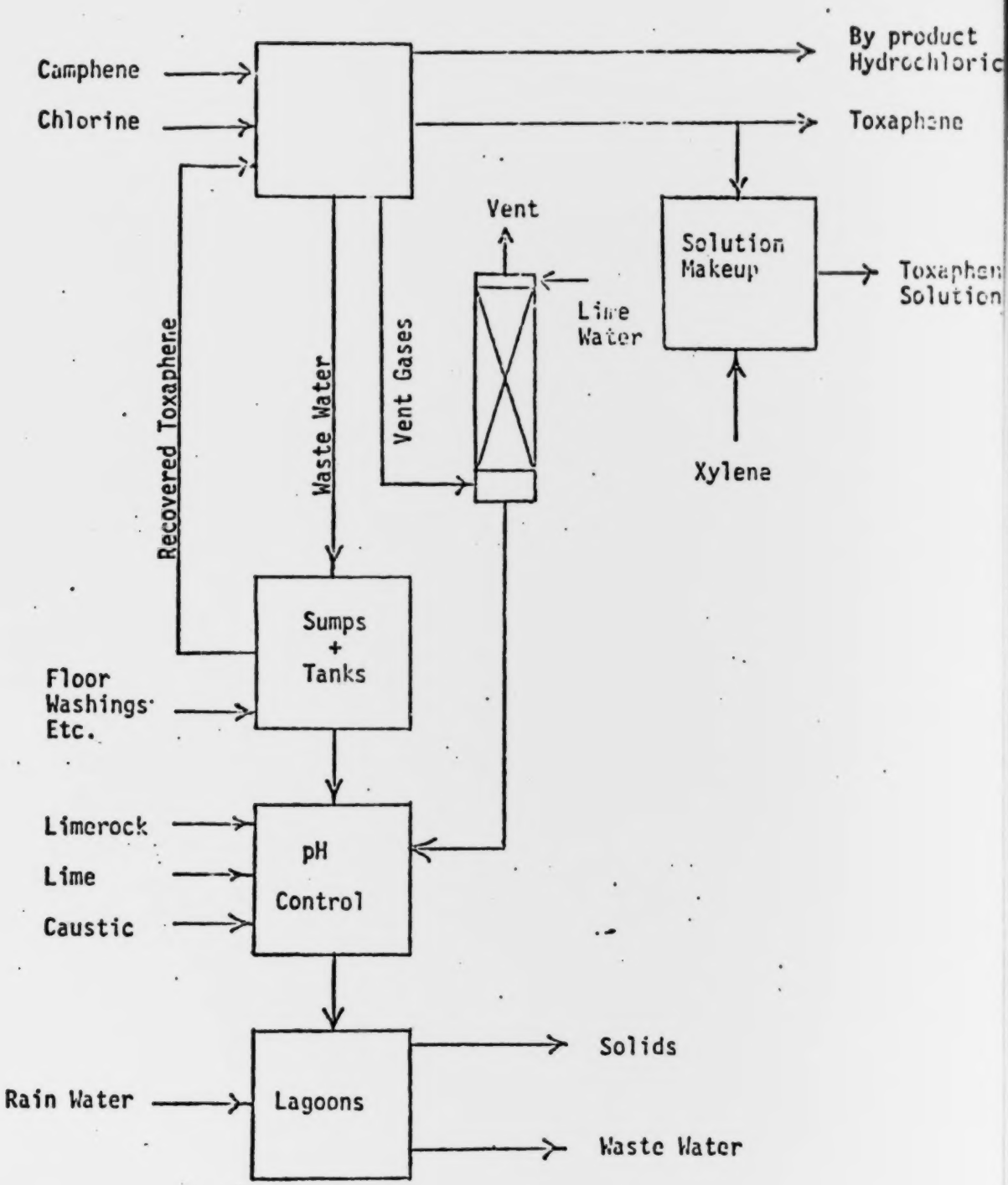

Figure A-1. Hercules toxaphene process schematic

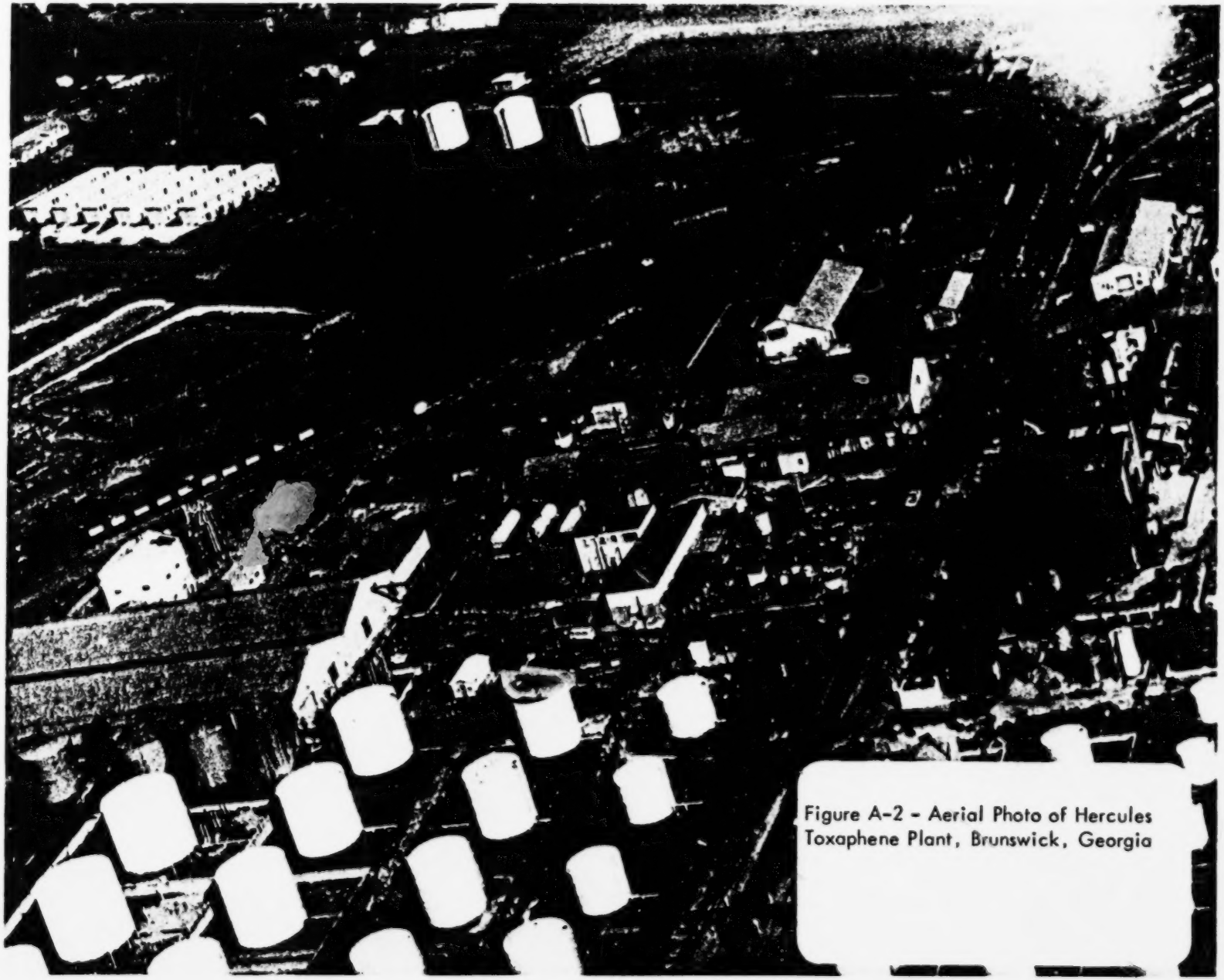

Figure A-2 - Aerial Photo of Hercules Toxaphene Plant, Brunswick, Georgia

these facilities are extensive. After the process wastewater is passed through the settling tank for recovery of free toxaphene, the wastewater stream is passed through several parallel limerock basins. Contact with crushed limerock neutralizes the bulk of the acidity. The effluent from the limerock basins is then combined with spent scrubbing liquors from the vent scrubbers and the pH of the combined streams is adjusted with caustic in a two-stage stirred tank. The heart of this pollution abatement design centers on the fact that toxaphene is strongly adsorbed on inorganic particulate matter originating in the limestone, lime and caustic neutralization steps. A great deal of work was carried out on both a laboratory and pilot scale to develop and prove in the effectiveness of this abatement process.

4. Solids Separation

All wastewater, after pH adjustment, is passed through a series of lagoons to settle out suspended solids. Rainwater from the rainwater lagoon is mixed with the influent to the solids separation lagoons. Solids separation is of course an essential feature of any pollution abatement system. In this case, however, solids separation serves a dual purpose. As noted above, because of the hydrophobic nature of toxaphene, the toxaphene present in the wastewater is strongly adsorbed on the separated solids. The source of the solids in the wastewater is the inert sand and clay present in the limerock used for neutralization. An aerial photo of the lagoon system can be found in Figure A-3.

5. Solid Waste Disposal

The solids collected in the lagoons are disposed of by landfill. The landfill operation is operated under permit from the Gerogia Department of Natural Resources.

6. Miscellaneous

a. A special housekeeping crew is used to clean up spills, clean sumps and to maintain the high level of cleanliness necessary to meet the difficult effluent standard.

b. Essentially all maintenance is done within the contained area. If it is absolutely necessary to remove a piece of equipment from the contained area, it is thoroughly decontaminated.

c. Analyses are run in a separate laboratory. Unused samples are returned to the process. Sample containers are recycled without cleaning when possible. If not possible, disposable containers are used.

C. Design Criteria

The pH control system was essentially in operation before issuance of the permanent NPDES permit. Capacity and design are largely based on operating experience. The design criteria for the lagoon system is as follows:

	Influent	Effluent
Flow	300 gpm	300 gpm
Toxaphene	2,000 ppb toxaphene	200 ppb toxaphene
Solids	4-10 tons/day	Negligible
pH	Approximately neutral	Approximately neutral

The controlling design criteria was a maximum of 1 lb/day of toxaphene in the total plant effluent. Because of uncontrolled sources of toxaphene, the effluent from the lagoon must contain significantly less than 1 lb/day of toxaphene.

The influent to the lagoons is extremely variable and the limerock used for neutralization contains variable amounts of inert solids. Because of this variability and the difficulty of accurately sampling this mixture, the influent is not routinely sampled. The effluent is, however, sampled daily. In addition, the total plant effluent composed of the toxaphene waste plus all other process wastewater, is also sampled daily. This sampling is at the outfall designated 001. Reports are submitted to state and federal authorities at monthly intervals.

D. Method of Operating

Sumps and settling tanks are cleaned as needed and the recovered toxaphene returned to the appropriate process step. Limerock is fed to the system as needed by conventional conveying equipment. Caustic or acid is added to the influent to the pH adjustment facilities automatically as needed to achieve the desired pH. The desired pH is normally slightly acidic since a higher pH results in unnecessary difficult-to-settle hydroxides. Because of the relatively small quantity of toxaphene wastewater, compared to the total plant effluent, the slight acidity of the toxaphene effluent stream is insignificant.

Rainwater runoff surges are impounded in the rainwater lagoon and the rainwater is then mixed with the process wastewater at a uniform rate. The rainwater runoff is essentially neutral and requires no other treatment.

The present method of operating the lagoons is to pass the wastewater through two lagoons in series. The lagoons presently being used are baffled so as to divide them in half. Essentially, they are now the equivalent of four lagoons in series. The lagoons not now in service contain solids collected in prior service and are dewatering. These solids will be transferred to the drying bed in the near future prior to transporting to the landfill site. Figure A-3 clearly shows the drying bed (partially empty), the two lagoons in active service, the two lagoons dewatering and the rainwater lagoon.

E. Chemical Additive Rates

The only additives used are the alkalies used for pH control. In theory, about 0.67 lb of hydrochloric acid or equivalent must be neutralized for each pound of toxaphene produced. Some acid is sold and need not be neutralized. Some of the waste acid is neutralized in the vent scrubbers by caustic or lime and the balance is neutralized by lime, limerock or caustic. In 1974, consumptions of the various alkalies per pound of toxaphene were:

Lime	0.05 lb/lb
Caustic	0.016 lb/lb
Limerock	0.51 lb/lb

F. Pollution Abatement Efficiency

The design toxaphene abatement efficiency for the lagoon system was about 90%. The actual efficiency is probably greater than 95%. Containment and meticulous control of leaks and spills in process and materials handling has resulted in an appreciable lowering of the toxaphene load presented to the lagoon system.

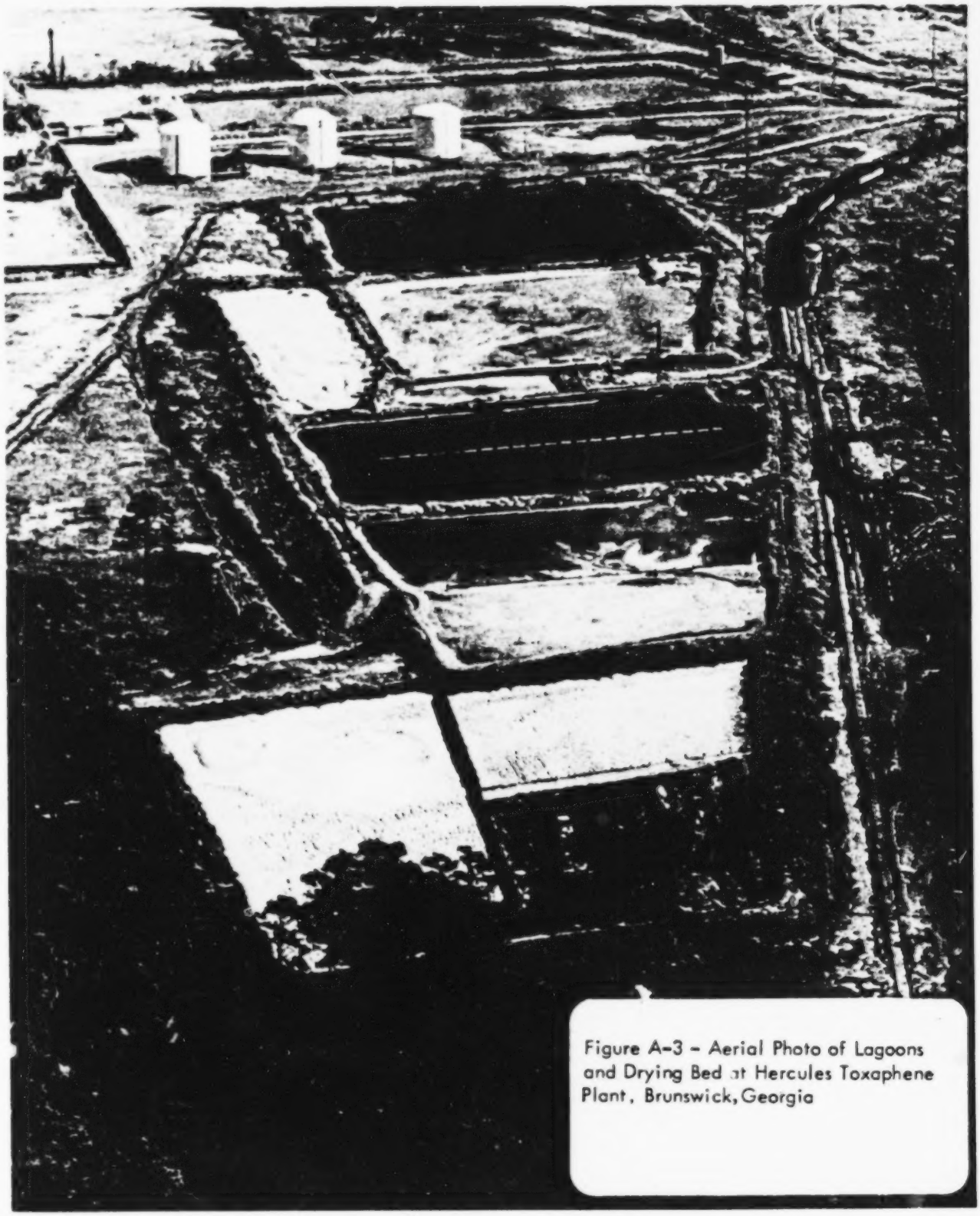

Figure A-3 - Aerial Photo of Lagoons and Drying Bed at Hercules Toxaphene Plant, Brunswick, Georgia

APPENDIX B

DEFINITION OF TERMS AND DISCUSSION OF CONVENTIONAL ENGINEERING PRACTICES USED IN ESTIMATING COSTS OF PESTICIDE WASTEWATER TREATMENT PROCESSES

Several terms used in the cost estimates require further definition and have been placed in this appendix to avoid a lengthy discussion in the text of the report. The terms which are defined and discussed in this appendix are (a) limits of error for cost estimates, (b) cost indexes, (c) six-tenths factor, (d) one-fourth factor, (e) payroll charges, (f) operating supplies, (g) control laboratory costs, (h) maintenance and repairs, (i) depreciation, (j) capital cost, (k) plant overhead, and (l) contingency for capital investment.

LIMITS OF ERROR FOR COST ESTIMATES

The probable limits of error for the study cost estimates in this report range from 30% above to 30% below the actual costs. Study cost estimates are commonly used to estimate the economic feasibility of a project before expending significant funds for piloting, market studies, land surveys, and requisitions. They may be off by 30% but they can be prepared at relatively low costs using minimum data as follows (see Figure A-1).

Location of site;

Rough sketches of process flow;

Preliminary sizing and material specifications of equipment;

Approximate sizes of buildings and structures;

Rough quantities of utilities;

Preliminary piping;

Preliminary motor list; and

Engineering and drafting man-hours.

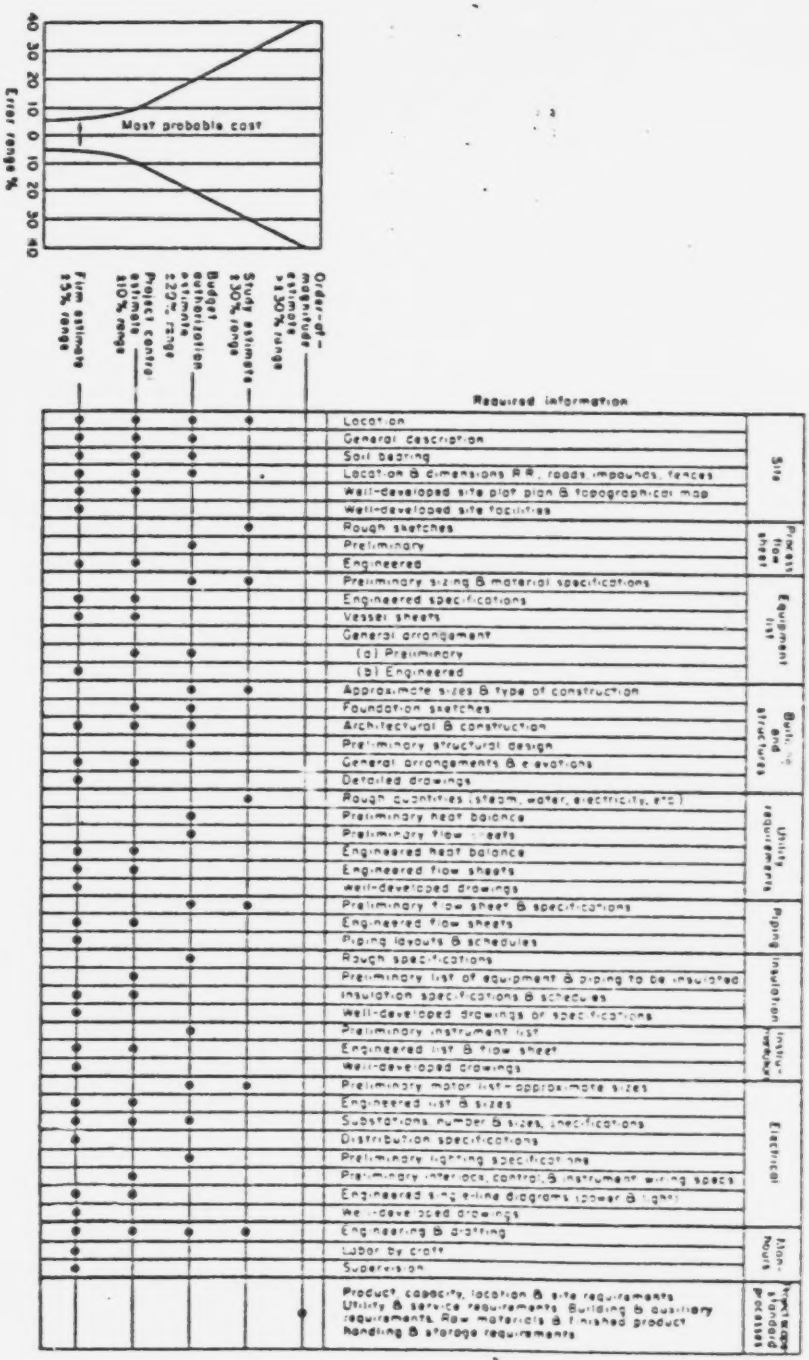

Figure B-1. Estimating Information Guide

COST INDEXES (Peters and Timmerhaus, 1968)

Most cost data which are available for immediate use in a preliminary or predesign estimate are based on conditions at some time in the past. Because prices may change considerably with time, due to changes in economic conditions, some method must be used for converting costs applicable at a past date to equivalent costs that are essentially correct at the present time. This can be done by the use of cost indexes.

A cost index is merely a number for a given year showing the cost at that time relative to a certain base year. If the cost at some time in the past is known, the equivalent cost at the present time can be determined by multiplying the original cost by the ratio of the present index value to the index value applicable when the original cost was obtained.

$$\text{Present cost} = \text{original cost} \frac{\text{index value at present time}}{\text{index value at time original cost was obtained}}$$

Cost indexes can be used to give a general estimate, but no index can take into account all factors, such as special technological advancements or local conditions. The common indexes permit fairly accurate estimates if the time period involved is less than 10 years.

Many different types of cost indexes are published regularly.

Engineering News-Record Construction Cost Index

Relative construction costs at various dates can be estimated by use of the Engineering News-Record construction index. This index shows the variation in labor rates and materials costs for industrial construction. It employs a composite cost for 2,500 lb of structural steel, 1,088 fbm of lumber, 6 bbl of cement, and 200 hr of common labor. The index is usually reported on one of three bases: an index value of 100 in 1913, 100 in 1926, or 100 in 1949.

Marshall and Swift (Formerly Marshall and Stevens) Equipment-Cost Indexes

The Marshall and Stevens equipment indexes are divided into two categories. The all-industry equipment index is simply the arithmetic average of the individual indexes for 47 different types of industrial, commercial, and housing equipment. The process-industry equipment index is a weighted average of eight of these, with the weighting based on the total product value of the various process industries. The percentages used for the weighting in a typical year are as follows: cement, 2; chemicals, 48; clay products, 2; glass, 3; paint, 5; paper, 10; petroleum, 22; and rubber, 8.

The Marshall and Stevens indexes are based on an index value of 100 for the year 1926. These indexes take into consideration the cost of machinery and major equipment plus costs for installation, fixtures, tools, office furniture and other minor equipment.

Chemical Engineering Plant Construction Cost Index

Construction costs for chemical plants form the basis of the Chemical Engineering plant construction cost index. The four major components of this index are weighted in the following manner: equipment, machinery, and supports, 61; erection and installation labor, 22; buildings, materials, and labor 7; and engineering and supervision manpower, 10. The major component, equipment, is further subdivided and weighted as follows: fabricated equipment, 37; process machinery, 14; pipe, valves, and fittings, 20; process instruments and controls, 7; pumps and compressors, 7; eletrical equipment and materials, 5; and structural supports, insulation, and paint, 10. All index components are based on 1957 to 1959 = 100.

SIX-TENTHS FACTOR (Perry and Chilton, 1973)

Cost estimates in this report are given for processes that require scaling up from a given capacity to a larger capacity (e.g., 100 gpm to 300 gpm and 600 gpm). Equipment size and costs were shown to correlate fairly well by the logarithmic relationship known as the "six-tenths factor." The simple form of this method is:

$$C_n = r^{0.6}\, C$$

where C_n is the new plant cost, C is the previous plant cost, and r is the ratio of the new capacity to the old capacity.

This method is the best available for estimating the cost of the systems in this report since each system involves multiple pieces of equipment, piping, instrumentation, etc. The exponent actually ranges from

0.45 to 1.15 for different pieces of equipment, but in complex systems, such as the ones described in this report, estimating the new capacity cost for each piece of equipment is beyond the scope of this study.

Therefore, when scaling the costs up, for example, from a 100 gpm plant size to other plant sizes, the exponent 0.6 is used as an approximation of the scale-up factor for the entire system. In each case, some error may be involved using this method, but no other method is available for this study.

ONE-FOURTH FACTOR (Peters and Timmerhaus, 1968)

The "one-fourth factor" uses the same principle as the "six-tenths factor" with the exception that the exponent 0.25 is used instead of 0.6. This factor is used to scale up labor requirements from one plant size to a larger plant size, and takes into account the fact that larger plant sizes require less than proportional labor forces due to economies of scale.

PAYROLL CHARGES

These costs are the result of the many fringe benefits employees receive in addition to their salaries. Recent emphasis on these benefits in labor contracts make this cost substantial and it is steadily increasing with time. The sum of fringe benefits may add between 15 and 40% to the wage rate of employees (Perry and Chilton, 1973), and the percentage varies widely from company to company. In this report, payroll charges (fringe benefits) are estimated to be 30% of the wages paid to both labor and supervision.

OPERATING SUPPLIES

Operating supplies are items such as lubricating oil, instrument charts, etc., that are neither raw nor repair materials. The cost of these items is typically about 6% of operating labor (Jelen, 1970).

CONTROL LABORATORY COSTS

Depending on company practice and the type of project, operating costs may include several charges by other units of the company, e.g., charges by a control laboratory.

Laboratory costs may be estimated as a percentage of operating labor cost, in the range of 3 to 10%, but the complex situations as high as 20% (Jelen, 1970). Since treatment systems require more laboratory support than typical production processes, in this report the cost of these services is estimated to be 20% of operating labor costs.

MAINTENANCE AND REPAIRS (Peters and Timmerhaus, 1968)

A considerable amount of expense is necessary for maintenance and repairs if a plant is to be kept in efficient operating condition. These expenses include the cost for labor, materials, and supervision.

Annual costs for equipment maintenance and repairs may range from as low as 2% of the equipment cost if service demands are light to 20% for cases in which there are severe operating demands. The annual maintenance costs are given separately for each process in this report, and range from 5 to 15% of the capital equipment cost of the various processes.

DEPRECIATION

Depreciation is a periodic charge that distributes the installed capital investment cost over its expected service life. Instead of charging the cost of the equipment as an expense in the year of purchase, a portion of its cost is charged against revenues each year throughout its estimated useful life.

In this report the estimated useful life is determined by using the arithmetic average of the high and low lifetimes of equipment when a range is given, or 10 years if the useful life is unknown. In some cases, the useful life may be too high by U.S. Treasury Department Standard Guidelines (such as the 40-year life for the sedimentation process) which allows an 11 year depreciation for chemical plant equipment (Perry and Chilton, 1973). However, using 11 years for all equipment would either understate or overstate the real cost in most circumstances. When the useful life is unknown, 10 years is used to conform to the guidelines of the federal government.

A zero salvage value is assumed in all depreciation estimates and straight-line depreciation is used.

CAPITAL COST

Regardless of whether the capital investment is to be obtained from company funds or made available by bankers, it is logical that the invested capital earn a fair interest. If the company funds are not used

for the new unit, then they could be invested to bear a reasonable interest. If the capital is raised by issuing bonds or by borrowing from another corporation, interest would be paid the investor. It should be pointed out that in order to offer a company the incentive to invest its money in a new plant, it should be able to realize as large an interest rate as it could earn by making other investments. Since the risk is somewhat higher than certain conservative investments, the interest rate should be higher than that offered by these securities. Excessive interest rates are not realistic in view of today's regulatory laws. Normally, an interest rate of from 6 to 8% on the unpaid principal is considered satisfactory.

In computing interest, it is necessary to remember that the amount of interest will decrease each year since the unpaid balance is reduced by the depreciation allowed the previous year. An interest rate of 10% would average approximately 6.3% of the total principal each year if the principal is repaid in 10 annual installments. It is customary to express the interest as a uniform fixed cost item each year.

An interest rate of 10% is used in these estimates based on the cost literature (Chemical Engineering, 1975).

In reality, the interest will decline each year and, therefore, the payment on the principal will increase if uniform principal plus interest payments are made. Uniform payments for n periods required to pay the original sum P can be computed from the following equation (Petroleum Refiner, 1957).

$$R = P\frac{i(1 + i)^n}{(1 + i)^n - 1}$$

where P = original sum

R = uniform periodic payment

n = number of payments

i = interest rate as fraction per period

The expression $(1 - i)^n$ is the compound interest expression found in table form in many handbooks (Lange, Handbook of Chemistry). Value of $i(1 + i)^n/(1 + i)^n - 1$ for various values of n and i are listed below (Petroleum Refiner, 1957).

Values of $\frac{i(1 + i)^n}{(1 + i)^n - 1}$

n	2%	4%	6%	8%	10%
1	1.020	1.040	1.060	1.080	1.100
5	0.212	0.225	0.237	0.250	0.264
10	0.111	0.123	0.136	0.149	0.163

If the original investment was $1,000,000 and the loan was at 10% interest for 10 years, the uniform payment would be

$$R = (1{,}000{,}000)\frac{0.1(1 + 0.1)^{10}}{(1 + 0.1)^{10} - 1}$$

$$R = 163{,}000$$

In 10 years the total payment would be $1,630,000. Thus, the total interest is $630,000 and the average interest rate would be

$$\frac{630{,}000}{10(1{,}000{,}000)} = 6.3\%/\text{year}$$

PLANT OVERHEAD

Plant overhead is a charge to the costs of the manufacturing facility which are not chargeable to any particular operation and are normally charged on an allotted basis. Overhead includes such cost items as plant supervision, plant guards, janitors, cafeterias, administrative offices, accounting, purchasing, etc. Overhead costs will vary from company to company and are usually calculated as a percentage of direct labor cost or a percentage of installed capital investment for the entire facility, and allocated to each operation based on its labor or investment cost.

Plant overhead can range from 40 to 60% of direct labor costs or 15 to 30% of direct costs (Jelen, 1970). We estimate that plant overhead is 20% of direct costs in this report.

CONTINGENCY FOR CAPITAL INVESTMENT (Fowler, 1975)

The selection of a contingency figure for an estimate is a matter of the judgment of the estimator. This judgment must consider several factors, such as:

(1) Data basis--laboratory, pilot or plant

(2) Allowance for inflationary trends

(3) Knowledge of construction costs at plant location

Under favorable conditions, the contingency factor may be as low as 10%. However, lacking actual plant cost and considering present inflationary trends, a contingency figure of 30% would be justified.

In the past, cost indexes have been a reliable method of estimating cost based upon plant costs in earlier years. The plant indexes are more reliable when used on plant cost rather than pilot plant costs. It is much more difficult to use them successfully when equipment is pilot plant size or when a small amount of equipment is used. The use of the indexes in the last 2 years has not been as accurate as in the past and can result in too low a plant estimate. Uncertainty increases if cost indexes are used to update plant estimates rather than actual costs.

Unless the estimator has made the original estimate or knows what the plant costs include, a large amount of uncertainty exists when projecting plant costs to other plant capacities and times. It is necessary to know whether a plant investment includes the cost of utilities, such as a steam boiler or cooling tower, or whether steam and utilities are available at the battery limits of the unit in any amount required. It is also important to know whether the plant investment includes the cost of the land and site preparation. Only if these factors are known can the contingency factor be kept to a reasonable figure of 30% or lower.

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